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ANALYSIS OF A PROPOSED MATERIAL
HANDLING SYSTEM USING A COMPUTER
SIMULATION MODEL

Darwin D. Harp, GS-11

LSSR 32-81

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A new mechanized material handling system (MMHS) will be installed in the supply warehouse at Newark Air Force Station, Ohio, in Fiscal Year 1982. The purpose of this research was to analyze the proposed system's behavior under simulated operating conditions prior to system installation. A Q-GERT simulation model was developed to study the various server and queue configurations associated with the MMHS. The analysis revealed that under simulated normal operating conditions the proposed system will perform as designed, and that a 25 percent surge in operating conditions will have significant effects on the system. Problem areas discovered in the proposed MMHS were identified to assist the managers of the system in implementation and future planning.

LSSR 32-81

ANALYSIS OF A PROPOSED MATERIAL HANDLING SYSTEM USING A COMPUTER SIMULATION MODEL

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Darwin D. Harp, BSIE
GS-11

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Mr. Darwin D. Harp

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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Thomas C. Harrington
COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Background

The Aerospace Guidance and Metrology Center (AGMC) at Newark, Ohio, has a threefold mission (5:3).

1. AGMC accomplishes single point repair of inertial guidance systems for aircraft and missiles for the Air Force and other DOD agencies.

2. AGMC provides engineering consultant and support services for inertial guidance systems when requested by cognizant engineering activities.

3. AGMC establishes, maintains, and performs overall technical direction and management of the Air Force Metrology and Calibration Program. The center, also, operates the Air Force Measurement Standards Laboratories as part of this program.

The primary mission of the 2803d Air Base Group Supply and Transportation Division (AGMC/DM) is to provide supply support to AGMC. This mission differs from that of the conventional base supply organization. Normally, the Air Force employs a Standard Base Supply System (SBSS) using the UNIVAC 1050-II computer to provide base level supply support to field activities. However, AGMC/DM uses

this system to support the sophisticated requirements at AGMC, thus being the only SBSS in the world supporting a depot level maintenance repair facility (2:3).

The Material Storage and Distribution Branch (DMSDR) and the Transportation Branch (DMTP) of AGMC/DM perform the physical and administrative functions connected with the receiving, warehousing, distribution, packaging, and shipping of material at AGMC. These two branches are located in buildings 4WD2 and 4WD9 adjacent to the main production facility (Figure 1).

Buildings 4WD2 and 4WD9 are relatively new, having been constructed in 1977. The material handling equipment owned by AGMC/DM at that time was not adequate for the new facilities' material flow and processes. Salvage equipment was obtained from Warner-Robins AFB, Georgia, and adapted into a functional layout for the new facilities. This equipment consisted of heavy-duty live roller conveyors and gravity roller conveyors.

Between 1977 and 1979, the material handling equipment and the warehouse layout presented many problems.

1. Many discrepancies in material handling procedures and poor space utilization were identified by Inspector General audits (5:69).

2. Safety and fire hazards were discovered periodically (5:70).

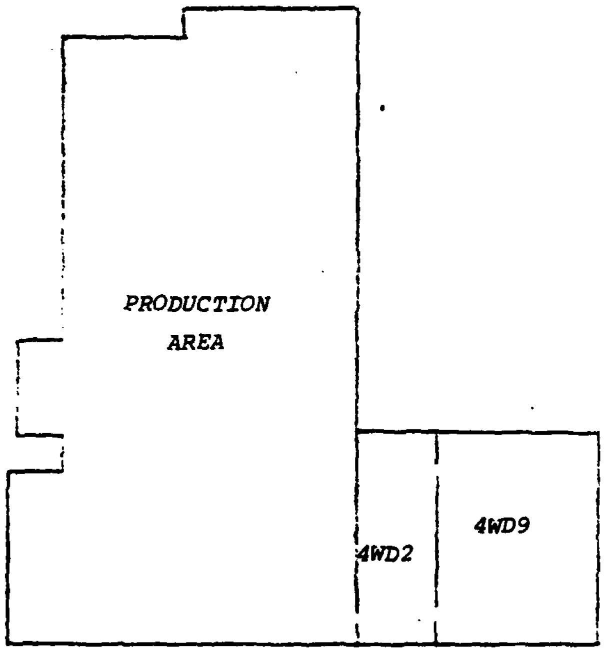

Fig. 1. Building 4 Floor Plan

3. Congested work areas resulted in inefficient work methods, low morale, and low productivity.

4. The age and size of the conveyors were not conducive to layout change and flexible working procedures, thus preventing system improvements with the existing equipment.

Various section chiefs attempted to solve these problems in their individual areas. These measures usually gave suboptimal results. The small improvements in their areas were at the expense of creating new problems in other warehousing functions.

In 1979, two incidents occurred relating to the material handling problem in the supply warehouse. First, the Plans and Programs Directorate (AGMC/XR) enlarged their industrial engineering staff from one to four people. This provided increased industrial engineering support to all non-maintenance organizations, such as AGMC/DM. Secondly, the industrial engineering group was introduced to the material handling problem by the supervisor of the Storage and Issue Section. After an initial investigation, the decision was made to develop an improved material handling system for the entire warehouse area.

AGMC/XR and AGMC/DM jointly submitted a proposal for a comprehensive material handling system for buildings 4WD2 and 4WD9. This proposal was accepted by the AGMC

management and AFLC in February, 1980 and, presently, is included in the AFLC budget for fiscal year 1982.

The proposed system presents a radical change in material handling methods and procedures for AGMC/DM. New equipment is to include conveyors, both live roller and gravity roller, a wire-guided stock-picker system, hydraulic lift tables, gravity-flow storage racks, and various types of individual work station equipment. The physical layout of the warehouse will be improved by changing the direction of the flow of material, developing new methods for moving material, repositioning computer terminals, relocating the administrative offices, constructing new mezzanine storage areas, and arranging storage racks to increase effective storage space.

Problem Statement

Dr. John A. White's Material Handling System Equation approach was utilized in solving supply's material handling problems (14:A-6).

MATERIALS + MOVES + METHODS = PREFERRED SYSTEM

By answering pertinent questions about each element in Dr. White's equation in relationship to the material handling problems, a theoretical, preferred system was developed. The theoretical system was analyzed using the guidelines prescribed in Air Force Regulation (AFR)

71-11, Air Force Mechanized Materials Handling Systems (12:9). Compliance with AFR 71-11 requires a detailed description of the proposed system and an economic analysis.

The proposed material handling system is believed to be sound and functional, but this belief is based mainly on theoretical evidence, prior material handling experience, and common sense. Because of time constraints on the system's designers, an in-depth analysis of the entire system was not possible. Therefore, it would be advantageous to analyze the system's behavior under simulated operating conditions before actual installation of the system.

Research Objectives

The objective of this research is to test the material handling system's behavior under simulated operating conditions before installation of the system. Since the system is not in operation, this research becomes a test of design characteristics. The system's structure, which is comprised of a series of interdependent and independent processes working towards a common goal, is extremely complex. To thoroughly understand the problem and research objective, one must comprehend the system's internal workings. This understanding is especially important due to the system's complexity.

Scope

The material handling system consists of the following functions or operations:

1. The receiving of goods and materials from either external or internal sources.

2. Storage of material.

a. inertial guidance systems to be repaired (reparable systems)

b. inertial guidance systems that have been repaired and are awaiting shipment (serviceable systems)

c. parts used in the repair process

d. normal supply material for base support

3. Packaging of material.

a. serviceable systems for shipment

b. material for long-period storage

c. normal material for shipment

4. Issuing and distribution of the material from the warehouse to the production area.

5. Loading and unloading of trucks.

6. Administrative and data processing support for the first five functions.

The six broad functions are interrelated as illustrated in Figure 2.

The changes in methods and procedures and introduction of new equipment have major effects on only a portion of the entire system. The physical movement of

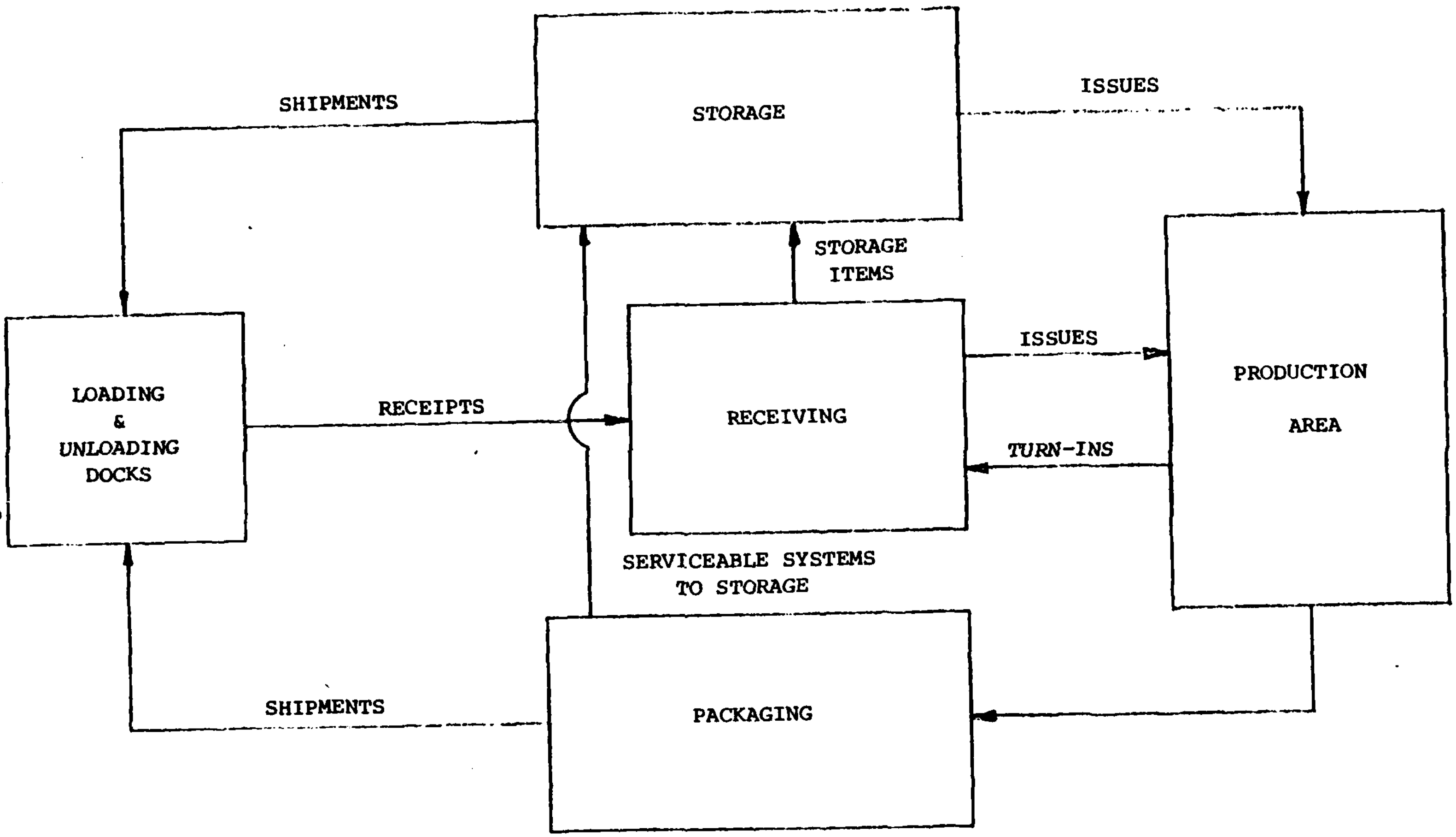

Fig. 2. Warehouse Process

materials to and from the production area is not a part of the proposed system. The modifications within the packaging area consist of updating the equipment, bringing packaging supplies closer to the work stations, and combining certain individual tasks. These improvements, although important to the packaging function, have little effect on the other portions of the material handling system. The function of the dock crew in loading and unloading of trucks is, also, not greatly affected by the proposed system.

Because of the small amount of change or influence on the whole system, the packaging function, dock crew activities, and the physical movement of materials to and from the production area have been omitted in this research. The emphasis of this study falls on the receipt, storage, and issue of material. Figure 3 displays the interactions of the receiving, issuing, and storage processes. Figure 4, an iconic model depicting the physical layout of the proposed system, illustrates the flow of material through these processes in the warehouse system.

The receiving process consists of four tasks: opening the packages, verifying the documentation, inspecting the material, and recording items into the supply inventory system. There are five classifications of material that can pass through receiving.

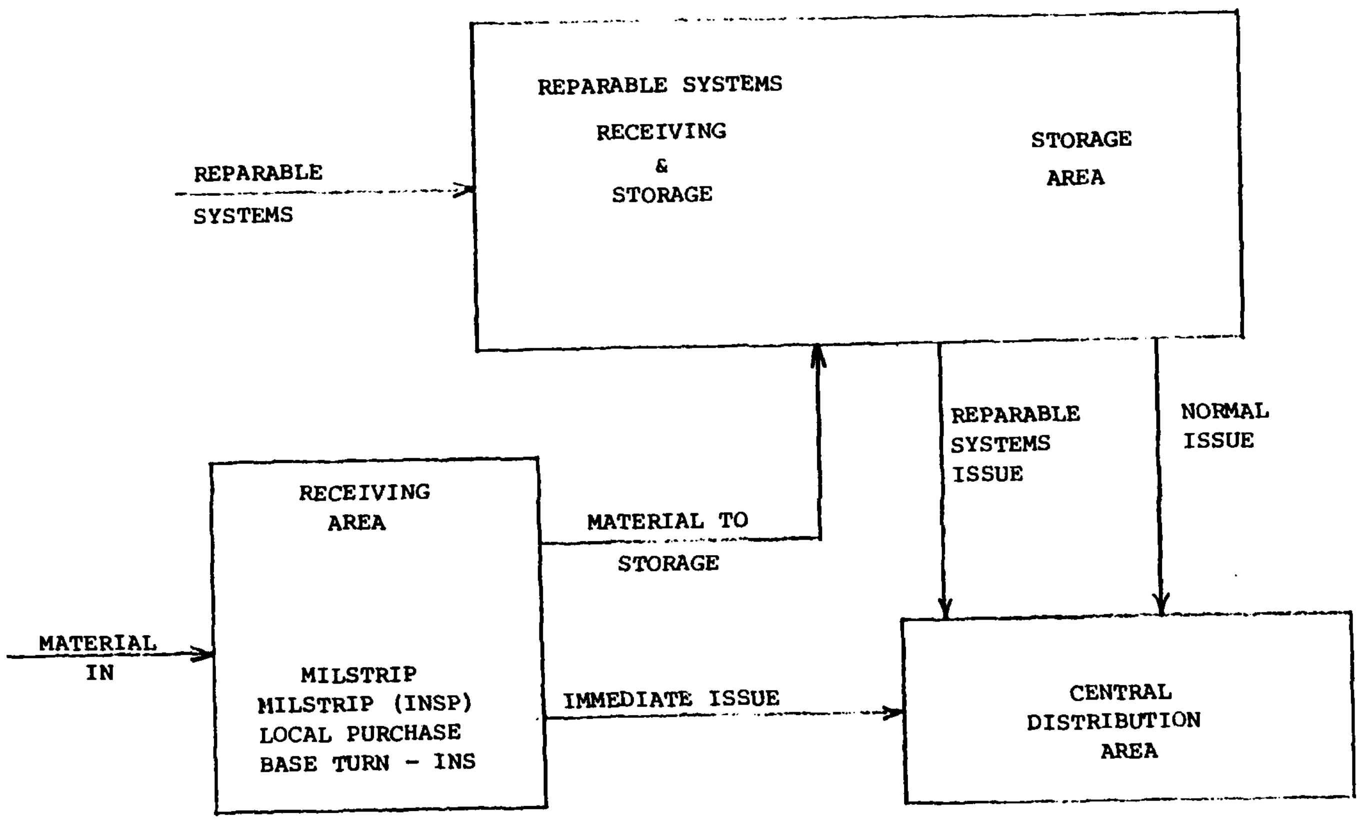

Fig. 3. Receiving, Storage, and Issuing Processes

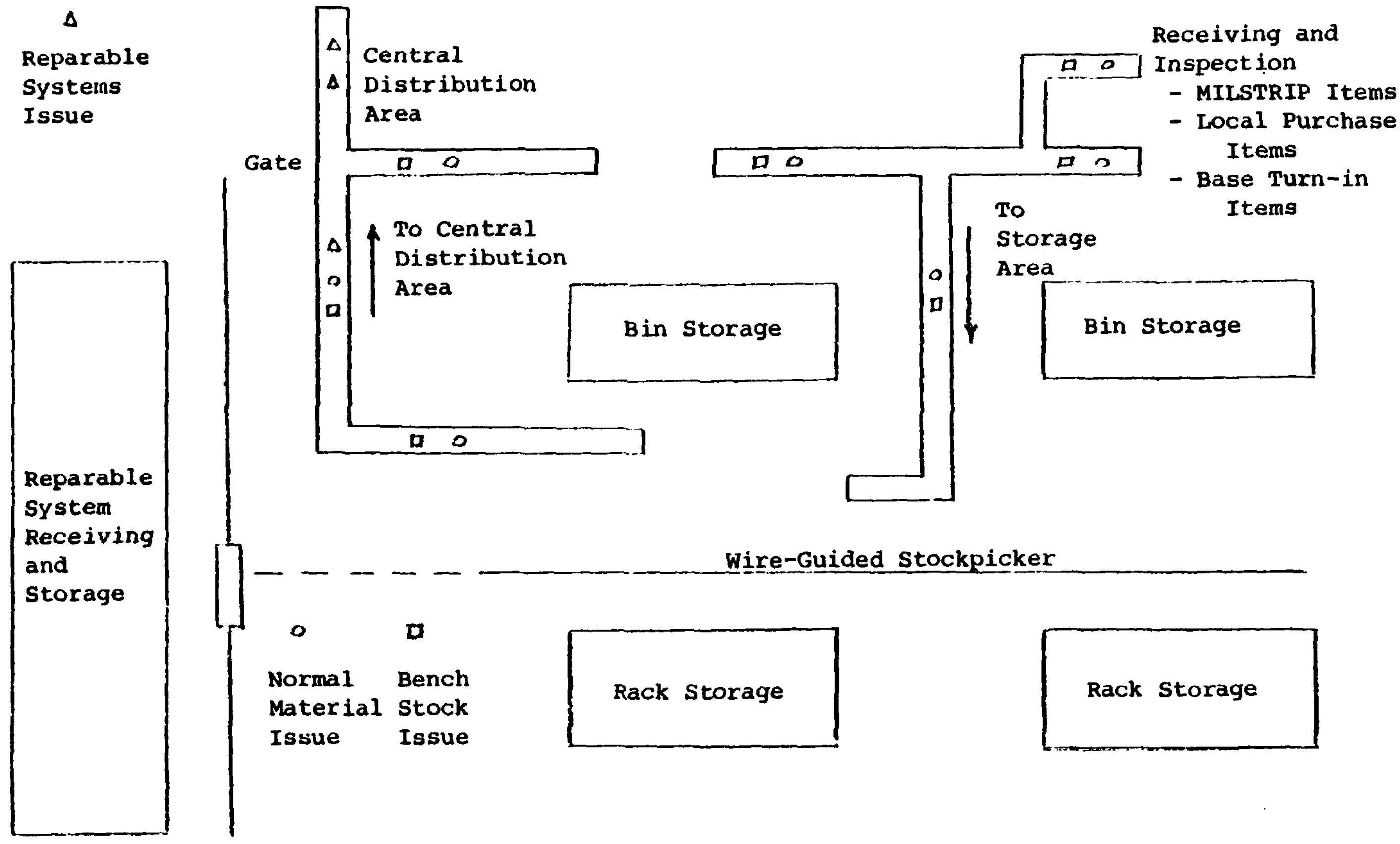

Fig. 4. Proposed Material Handling System and Warehouse Layout

1. Military Standard Requisition (MILSTRIP) material--material acquired from government sources.

2. MILSTRIP requiring inspection--MILSTRIP material such as paint, chemicals, and flammables that require inspection.

3. Local Purchase--material from private vendors.

4. Base Turn-ins--material coming from internal sources at AGMC.

5. Reparable Systems--inertial guidance systems to be repaired at AGMC, which are received in the storage area because of their size and quantity of shipment.

Once the receiving process is completed, the material moves by powered conveyor directly to the central distribution area, to be picked up for delivery provided a request has been identified by the computer. Otherwise, the material flows into the storage area, also by powered conveyor, where it is assigned a bin or rack location depending on its size. When an issue document is generated by computer to the storage area, the material requested is retrieved and conveyed to the central distribution area for delivery.

All material, except the reparable systems, follows these paths. Because of their size and quantity of shipment, reparable systems are moved by forklift directly to the storage area for processing into the supply inventory. Once a computerized issue document is received in the storage

area, the reparable system is retrieved and conveyed to the central distribution area for delivery. It is important to note that normal material issues and reparable system issues are transported by the same conveyor to the central distribution area. Upon arrival at the central distribution area, the reparable systems are separated from the normal material by an electric eye-gating device in order to facilitate further processing.

A series of sequential processes can be recognized within the proposed system. Because the demand on these processes or services exceeds the current capacity to provide that service, queues or waiting lines precede the processes (1:379). The system, therefore, is comprised of a series of sequential processes with their respective queues.

Research Questions

The system's behavior under operating conditions becomes the queue characteristics at strategic points in the system (1:598). Research questions to determine the queue characteristics are directed at the following queues and respective processes.

1. Receiving section
    a. MILSTRIP
    b. MILSTRIP (inspection)
    c. Local Purchase

d. Base Turn-ins

e. Reparable Systems

2. Storage Section

a. Material arriving to be stored

b. Issues of material

c. Issues of reparable systems

3. Central Distribution Area

a. Material incoming for pick-up and delivery

The research questions are:

1. What is the maximum amount of material in the specified queues under normal operating conditions (predicted receipts and issues)?

2. What is the average amount of material in the specified queues under normal operating conditions?

3. Is there sufficient space for the queueing of materials under normal operating conditions?

4. What are the answers to the first three questions if, instead of normal operating conditions, a surge in the workload (25 percent increase in receipt and/or issues) was experienced?

In studying the queue characteristics, the processes following the respective queues also come under scrutiny. The research questions imply investigation in server utilization and idle time. Servers, in these instances,

refer to the warehousemen or inspectors performing the processes.

Assumptions

Certain assumptions were made at the beginning of this research to facilitate the study.

1. The proposed material handling system is dormant, awaiting AFLC funding. There will be no changes or modifications prior to installation that would negate this research.

2. If this research uncovers major problems, the proposed system is flexible and could be modified before installation.

3. All equipment will operate as denoted by the manufacturers' performance standards.

Limitations

Due to the complexities of the material handling system, the following areas were considered as limitations in this research.

1. As mentioned before, only those areas that appear to be more dynamic to the entire system are under study in this research.

2. There were no labor standards for the various processes in the DM warehouse area. Subsequently, process times were generated as a part of this study and their accuracy will be noted in a later section.

Justification

This research involves the development of a simulation model for the analysis of the proposed material handling system under simulated normal and surge operating conditions. There are three important benefits that are to be derived from this study. First, the simulation model will provide the managers and operators of the system with a great deal of knowledge concerning the behavior of the proposed system prior to implementation. This facilitates the transition and implementation phases and should enhance employee acceptance. Second, since experimentation, such as analysis of surge conditions, will be performed on the simulation model rather than on the real system, the supply and production operations do not have to be interrupted. Third, if potential problem areas are identified with the simulation model, there would be cost savings derived from their resolution prior to installation. Any problem or system malfunction detected after installation would be very expensive to correct, and in addition to cost, the correction would entail disruption of supply and production operations. Further, if the system faced problems immediately after installation, the employees' confidence in the system would be affected. For the new material handling system to be successful, the employees must demonstrate cooperation, not apathy or even contempt.

Definitions

A Glossary of Terms pertaining to DOD warehousing terminology appears in Appendix A.

Literature Review

The search for background information for this study was conducted in three areas.

1. Material handling in the warehouse functions.
2. Queueing theory.
3. Queueing theory applied to material handling.

The studies dealing with material handling in the warehousing functions were primarily concerned with the development or design of material handling systems. These studies are not helpful to this research since the proposed system is past the design stage.

Although queueing theory normally deals with specific queueing configurations and models, there are certain definitions and concepts that one must understand in order to appreciate this research.

A queue, by operations research terminology, is defined as a waiting line. The basic queueing system model, as indicated in Figure 5, consists of an input source (customer), a queue, and a server (6:381).

Queueing theory influences certain parameters in the simulation model developed in this research. The simulation model will be discussed in detail in a later

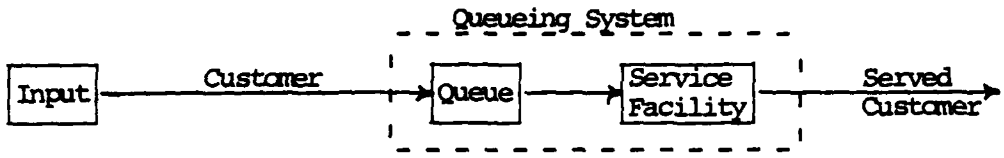

Fig. 5. Queue Model

section of this thesis; for now, a discussion of the aspects of queueing theory that are important to this study is pertinent.

The characteristics of the input source can affect the entire model. The arrival process must be defined as to size of the population from which it is drawn, that is, either infinite or finite population sources. The type of generating process for the arrivals, either deterministic or probabilistic, must be determined. The arrivals have to be classified as dependent or independent. These factors must be specified in the simulation model (6:379-382).

The queue configuration has to be defined in the model. Queue configuration refers to the number of queues and the relationship of the queue to the server. An example would be a single queue feeding into three parallel servers (6:381).

The service discipline pertains to the behavior of the server in accepting the customer. Accepting the customers on the basis of a priority system would be an example of service discipline. Identification of the service disciplines within the model is extremely important (6:381).

Finally, configuration of the service facility must be considered. Such factors as number of servers, the service time, and server arrangement must be defined for the model (6:381-382).

The many facets of queueing theory when assembled into a model become very complex and difficult to analyze. For this reason, most literature dealing with queueing theory applied to material handling analysis was on computer simulation models. As mentioned before, this topic will be discussed in a later section of this study.

CHAPTER II

METHODOLOGY

Overview

The complexity of the proposed material handling system makes analytical analysis very difficult. The combination of stochastic arrival and service rates, variable number of service facilities at each process, and the interrelationship between processes inhibit the representation of the proposed system by an analytical model. Even if an analytical model could be found or developed for this situation, it would be difficult to determine its applicability because of its mathematical complexity (1:615).

Phillips (9:65) offered the following advice on the problem:

> The primary reasons for the lack of predictive tools in the material handling arena probably stem from the fact that such systems, either in isolation or in relationship to the larger manufacturing environment, are extremely complex.
>
> In order to cope with stochastic, highly interactive, exogeneously driven material handling systems, the tools and techniques of digital systems simulation analysis seem to be the most desirable and often the only available systems analysis technique.

The complexity of the proposed system motivated the researcher to believe that computer simulation was the most practical method of analysis.

Modeling and Simulation

The definition of simulation, most useful in understanding the purpose of this project, is stated as:

> Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system [11:2].

The purpose of this project was to understand the behavior of the proposed material handling system.

Many unique advantages are obtainable in the use of simulation. Four of them are most important to this study. First, new policies and decision rules for operating a system can be experimentally tested by simulation before introducing them into the real system. The proposed material handling system will force changes in policies and managerial decision making in the warehousing system. These changes were incorporated into the model. The second advantage occurs when new equipment and procedures are to be introduced into the system. In this case, simulation can be used to determine bottlenecks and other problems that may arise during actual system operation. Another advantage is that the researcher has control of time in a simulation and that time can be compressed. Finally, simulation can be used to experiment with new situations about which we have little information, in order to prepare for what may happen (9:66).

There are also disadvantages associated with performing a simulation. The simulation may appear to represent the real world situation when it actually doesn't. Simulation is also imprecise and the degree of imprecision cannot be measured. Analysis of the sensitivity of the model to changing parameter values can only partially overcome this difficulty (11:13). Although there are disadvantages, simulation appeared to be the most practical method to accomplish the research objective in this study.

The simulation process is comprised of nine stages. These nine stages are listed with a brief description of each. Their relationship to this study will be covered later in greater detail.

1. System Definition--Determining the boundaries, restrictions, and measure of effectiveness to be used in defining the system to be studied.
2. Model Formulation--Reduction or abstraction of the real system to a logic flow diagram.
3. Data Preparation--Identification of the data needed by the model, and their reduction to an appropriate form.
4. Model Translation--Description of the model in a language acceptable to the computer to be used.
5. Validation--Increasing to an acceptable level the confidence that an inference drawn from the model about the real system will be correct.
6. Strategic Planning--Design of an experiment that will yield the desired information.
7. Tactical Planning--Determination of how each of the test runs specified in the experimental design is to be executed.
8. Experimentation--Execution of the simulation to generate the desired data and to perform sensitivity analysis.
9. Interpretation--Drawing inferences from the data generated by the simulation [11:23].

The nine stages are not sequential steps, but instead, interactive processes. The system being studied and the computer language used determine the method and order of accomplishing the nine stages of the simulation process.

System Definition

The first step in defining the system to be studied consists of specifying the goals and establishing the boundary conditions (that is, what is and is not a part of the system to be studied) (11:26). As indicated in Chapter I, the goal of this simulation study is to determine the behavior under operating conditions of the receiving, storing, and issuing activities of the proposed material handling system.

The system definition and boundary conditions were indicated in Chapter I. As stated, the packaging operation, dock crew activity, and the distribution of material from the warehouse to the production areas were omitted from this study since they have little effect on the proposed material handling system under investigation.

Material can be transported in the proposed system primarily by two methods. Forklifts handle the bulk material while the smaller material is moved by mechanized methods. These mechanized methods include conveyors and a wire-guided stockpicker. Both the wire-guided stockpicker

and conveyors indicated in the new system differ radically from the present operating procedures in the warehouse area. The only alteration in forklift procedures was to reduce it by 33 percent (5:67). This reduction was accomplished by utilizing mechanized methods when applicable. For this reason, the movement of bulk material by forklift is not considered a potential problem area and is omitted from this study. The increase in material movement by the new, untried mechanized equipment establishes the importance of this study.

Model Formulation

The model formulation step is directly related to the system definition step. Their relationship is such that both are accomplished almost simultaneously.

> A model is a representation of an object, system, or idea in some form other than that of the entity itself. Its purpose is usually to aid us in explaining, understanding, or improving a system [11:4].

The diagrams presented in Chapter I are pictorial models of the proposed material handling system (Figure 2) and the isolated portion that is being studied (Figure 4). "As an aid to communication, well thought out models have no peer. 'One picture is worth a thousand words' testifies to this function [11:6]." The model formulation enabled the focus of attention to be placed on the factors of importance that must be included in the simulation.

> When attempting to build a model, we could include an infinite number of facts and spend an endless amount of time gathering detailed facts about any situation and defining the relationships among them. Consequently, we must ignore most of the actual features of an event under study and abstract from the real situation only those aspects that make up an idealized version of the real event [11:17].

When the system to be studied was defined, in reality, the model was being formulated. The important facts and processes were included in the model and the insignificant facts were excluded.

Data Identification

Data input for the model can be classified as variables, which are further classified as independent and dependent (response) variables (2:31). In the warehouse system, three variables are identified as independent. The arrival rate of material to the receiving area for processing is an independent variable. This can be the arrival of trucks bringing reparable systems or other material and the arrival of material from on-base activities to be turned in to Supply. The arrival rate of normal issues to the storage area is another independent variable. This pertains to computerized requests from external sources for conveyable material other than reparable systems. The third independent variable is the arrival rate for issue of reparable systems. These are computerized requests from the production areas for initial guidance systems, located in storage, that are to be overhauled.

The response variables relate to the research questions introduced in Chapter I. The average and maximum amount of material contained in specific queues during simulated operating conditions and the utilization of the stockpicker comprise the response variables. There are four queueing areas of importance. One is the queue located before the receiving process. The second is the queue leading to the storage of conveyable material arriving from the receiving area. The third queue is before the central distribution area and is comprised of material for issue, both reparable systems and normal issues. The final queue of interest is the queue of computerized issue documents, both normal and reparable systems. The first three queueing areas are critical because of space consideration. If the space alloted in the system's design for the queueing of material at these points is not adequate, then the flow of material will be disrupted and the system will malfunction. If the queue of issues grows too large, the material going to base activities will be delayed and therefore the base activities will be impaired. The amount of time the stockpicker is utilized is also a response variable.
Its importance cannot be overemphasized. In many instances, it is the only piece of equipment that can easily reach stored material locations because of rack height or aisle width restrictions (5:68).

Data can also be labeled as parameters which are numbers or symbols that remain constant during the simulation run (2:31). Most of the parameters in this study are outside the control of the researcher. The queue configurations and number of servers at each individual process was dictated by layout design of the proposed material handling system. In addition, the positioning of conveyors, storage racks, and administrative offices was determined by the system designers. Therefore, queue configuration and the number of servers at each warehousing process were included in the model as parameters.

The service rate at each work station is controlled by the methods and procedures used by the warehousemen at that station. These times were considered as parameters in this research. The server discipline, that is, the order by which items are processed by the server, is governed by management decision. For the most part, items are processed using the first-in first-out (FIFO) technique. The only exception involves items deemed critical by management, which are handled by priority rules. Because the applied server discipline remains constant, it was also classified as a parameter.

Data Collection

Since the proposed material handling system will totally replace the present system, the data elements of

the present system will be the same as the ones for the proposed system. This fact facilitated data collection. The standard base supply system at Newark contains a comprehensive management information system. Data can be easily obtained, in most instances, from this information system.

The arrival times of both types of issues, normal and reparable systems, were collected by a simple random sample of the Single Line Item Release/Receipt Documents (DOD Form 1348-1) in the storage area. The date, time of issue, and item description are three pieces of data contained on the AF Form 1348-1 that were of interest. From these, the arrival rate and determination of conveyable or bulk material was projected. The arrival rate of trucks to the receiving area was obtained by randomly sampling the foreman's log for shipments received.

As indicated earlier, most of the parameters were determined by the warehouse layout. The queue configurations, number of servers, and server discipline was obtained from the design of the proposed material handling system (5:50-60). The service rate is actually the labor standard for that respective process or operation. The service rates were generated by using labor standards when the difference between the present and proposed processes were not distinguishable. This method was not always available because of the lack of labor standards for certain

processes which were either changed in the proposed system or did not have labor standards administered. For these operations new standards were built. The new standards resulted from analysis of the proposed methods and procedures using synthetic measurement such as Methods Time Measurement (MTM), manufacturer's specifications for equipment, interviews with knowledgeable people in the warehousing field, and actual time studies when the operation could be observed.

Data Analysis

The collected data elements were analyzed prior to computerization of the simulation model. The arrival rates were analyzed using the Chi-Square Goodness of Fit test to determine if the empirical data reasonably fit a theoretical distribution. If the empirical data could be represented by a theoretical distribution, then the theoretical distribution, with its estimated or specified parameters, was used in the model.

> The design of a stochastic simulation model always involves a choice of whether to use empirical data directly in the model or to use theoretical probability or frequency distributions. First, using raw empirical data implies that all one is doing is simulating the past. The use of data from one year would replicate only the performance of that year and not necessarily tell us anything about the expected future performance of the system. Second, it is generally more efficient of computer time and storage requirements to use a theoretical frequency or probability distribution rather than to use table look-up procedures for generating the necessary random variates for the model's operation [11:27-28].

The service rates at the individual processes were represented in the model by normal distributions because of the statistical foundation of the labor standards from which they were based.

Model Translation

Q-GERT was the computer language selected for this project. "GERT is an acronym for Graphical Evaluation and Review Technique. The Q is appended to indicate that queueing systems can be modeled in graphic form [10:vii]." "Basically, Q-GERT applications relate to queueing systems analysis or project planning and management [10:5]." Q-GERT was chosen for this simulation for two reasons. First, Q-GERT adapts well to simulating models involving queueing theory. Second, from a practical standpoint, Q-GERT is the simulation language predominantly used in AFIT School of Systems and Logistics courses and research.

A Q-GERT network is made of nodes and branches. Each branch represents an activity which involves a processing time or a delay. The nodes act to separate branches and are used to model milestones, decision points, and queues. Items that flow through the network are called transactions (10:3). Figure 6 is a graphic representation of the Q-GERT network.

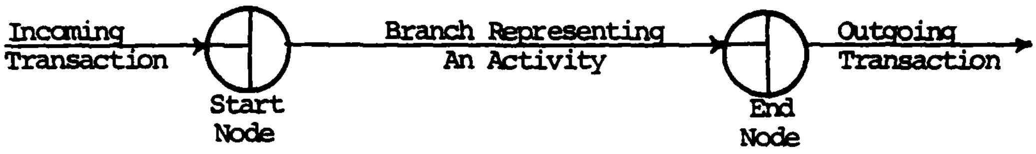

Fig. 6. Q-GERT Network (10:4)

For this project, material moving in the supply system such as receipts, issues, and reparable systems, are the transactions. The activities in this system are the servers or warehousemen performing individual operations at the work stations.

The Q-GERT computer program, once developed, was then verified. Verification means to ensure that the model behaves the way the experimenter intends (11:210). This process involved ensuring proper operation of the random number generator, checking the mathematical equations for accuracy and checking the program for logic errors (4:38). The Q-GERT diagnostic program component assisted in the verification process by analyzing and describing all logic errors as part of the simulation run.

Model Manipulation

The next phase consisted of determining the experimental design and the method by which it would be executed. "The experimental design selects a particular approach to gathering the information needed to allow us to draw valid inferences [11:145]." As indicated in Chapter I, the purpose of this research is to evaluate the behavior of the

proposed material handling system under simulated normal and surge operating conditions. To accomplish this purpose, the simulation was conducted using two separate models. The first model included normal operating conditions. This means that the input variables were set at values which were determined in the data analysis phase. The second model utilized the same computer program with an increase in the arrival rates of receipts, arrival rates of normal issues, and arrival rates of reparable system issues. The surge increase was believed to be appropriate for three reasons. The first reason is that normal growth over the next five to ten years could result in such an increase in operations. Second, such a surge rate could be realized during a period of conflict or war. Finally, the single point storage concept, which would involve centralization of all inertial guidance system inventories at Newark, could result in such an increase.

Validation of the model, which ensures that the behavior of the model agrees with that of the real system, is a very important process (11:210). However, while validation is very important, it is also very difficult to do precisely since "There is no such thing as the 'test' for validity [11:29]." The most obvious method to validate a model is to statistically compare it to the real system (11:227). Of course, in this research, that was impossible since the real system does not exist. The researcher

therefore had to rely on his expertise and the knowledge of the employees at Newark who were familiar with the proposed system, and the supply system in general, for validation of the simulation model. This researcher believes that his knowledge of the proposed system greatly enhanced the validation of the model since he was actively involved in designing the new system (5:1). Shannon (11:236) states that

> I firmly believe that the professional judgement of the people most intimately familiar with the design and operation of a system is more valuable and valid than any statistical test yet devised.

The tactical planning phase consisted of the resolution of two problems: (1) sample size, and (2) starting conditions/equilibrium (11:31). The sample size is important since it affects computer processing time and the degree of statistical inference that can be obtained from the model. The statistical testing procedure used in this study was the standardized normal test, which allowed comparison of the mean values of the selected response variables obtained from simulation runs under both normal and surge operating conditions. As will be discussed under the model analysis section of this chapter, the standardized normal test required sample sizes of at least 30. Thus, each simulation model was run 30 times to meet the requirements for the standardized normal test and to keep the computer processing time low.

The proposed system must be studied under a steady-state condition because the start-up operation would cause a distortion in the model. The real system would never be in an empty or start-up condition after implementation. Starting conditions that the researcher felt were typical of the system's steady state condition were used in the simulation. The stabilization period can be shortened (but not eliminated) if the initial starting conditions chosen are typical of the steady-state condition (11:184).

Model Analysis

Once the simulations were completed, they were analyzed by comparing response variable statistics under normal operating conditions to the respective statistics obtained under operating conditions with an added surge rate. The average and maximum sizes of queues for the receiving area, storage area, issue documentation, and distribution area, plus the stockpicker utilization factor were compared for the two operating conditions. This comparison was done by testing for a significant difference in the corresponding means. As mentioned before, a standardized normal test was utilized in each test of means. The standardized normal test is appropriate when the variances of the population is unknown and the sample can be assumed to approximate a normal distribution (11:220). The sample size of 30 allowed the researcher to invoke the central

limit theorem which states "For almost all populations, the sampling distribution of $\bar{x}$ is approximately normal when the simple random sample size is sufficiently large [8:202]." If no significant difference was detected between the two simulations, then they were analyzed as being equal. If they appeared to be significantly different, they were analyzed separately. In any case, the simulations were analyzed to determine if the space allocated for queueing of material in the identified areas was adequate. Accomplishing this meant equating the average and maximum amount of material in a queue to a volume of space and then comparing this theoretical volume to the actual space allocated in the layout design of the proposed system. The utilization of the stockpicker was examined to ensure that it never approached 100 percent. Although one wants to utilize the material handling vehicles as much as possible, a utilization rate much over 75 percent can be dangerous because of queue build-up and vehicle maintenance requirements (13).

Summary

This chapter described the methodology used to analyze the proposed material handling system at Newark AFS. A Q-GERT simulation computer model was developed and used to study the proposed system. The results of the simulation were analyzed in an effort to detect bottlenecks and problem areas in the system.

CHAPTER III

DATA COLLECTION AND ANALYSIS

Overview

Data collected for use in this study were basically of two classifications; the arrival rates of both receipts and issues into the system, and server rates for the various processes performed within the system. As indicated in the last chapter, parameters such as queue configuration, number of servers, and server discipline were functions of the proposed system and, therefore, were defined by the system design.

Arrival Rates

The arrival rate of trucks to the receiving area was determined by random sampling the dock foreman's log of shipments received. This sample of 1980 Fiscal Year data was converted into 344 one-hour periods. A Chi-Square Goodness of Fit test, with a significance level of .20, revealed that the sampled data could be assumed to come from a Poisson distribution with a mean of 1.82 truck arrivals per hour. Since the Q-GERT language cautions against using the Poisson distribution as an input parameter, it was necessary to transform the Poisson into an exponential distribution. The mean of an exponential distribution is the

inverse of the mean of the Poisson distribution (8:157). Therefore, the reciprocal of 1.82, or 33 minutes between truck arrivals, was used as the input in the receiving portion of the model. The Q-GERT language allows for the establishment of minimum and maximum times between arrivals to avoid unrealistic data generation by the simulations. These minimum and maximum times were obtained from the sampled data.

The management information system that provided a source of data for most of this research, tracks warehouse transactions in the form of line items. A line item simply refers to a single line entry in the supply inventory system. In order to maintain a commonality of measurement for variables and parameters in the model, the truck arrival rate had to be adjusted to represent a line item arrival rate. This was accomplished by comparing the number of line items processed by the receiving function, during a specific period, to the number of truck arrivals for the same period. The number of line items processed during the period previously sampled was obtained from the Daily Base Supply Management Reports. The data from the two-month period revealed that each truck arrival resulted in the generation of 25 line items in the receiving section.

The dock foreman's log revealed that for the sampling period, the truck transporting reparable systems to AGMC arrived at approximately the same time each day.

Further, the Transportation Section advised that this truck was scheduled to arrive at 1200 hours every day. This scheduled arrival time enables the same truck to be utilized for transporting both reparable systems to Newark and serviceable systems from Newark to Wright-Patterson AFB for entry into the air transportation system. The sampled data indicated that each truck arrival generated 80 reparable systems to the supply warehouse. Since the arrival of the truck carrying reparable systems was determined to be a scheduled or controlled variable, its arrival in the model was also controlled. The arrival rate of reparable systems was normally distributed around 1200 hours each day. The minimum and maximum constraints were set at 1100 hours and 1300 hours respectively. Each truck arrival constituted the input of 80 reparable systems into the model.

Normal issues, which are computerized requests from external sources for material other than reparable systems, had to be separated into two groups because of differences in arrival rates. While the arrival rate for normal issues generally followed a random distribution, those issues generated by the Bench Stock Section were found to be controlled.

The arrival rate of normal issues was determined by a simple random sample of the 1980 Fiscal Year Single Line Item Release/Receipt Documents (DOD Form 1348-1) in the

storage area. A Chi-Square Goodness of Fit test, with a significance level of .20, indicated that the arrival rate of normal issues could be assumed to come from a Poisson distribution with a mean of 18.75 issues per hour. Again, it was necessary to transform the Poisson distribution into an exponential distribution for use in the Q-GERT model. The transformation resulted in a rate of 3.2 minutes between arrivals of normal issues in the storage area. The minimum and maximum times between arrivals were taken directly from the sampled DOD Form 1348-1s.

The random sample of DOD Form 1348-1s also indicated that bench stock issues were received as a group on specific days. This resulted from the method used by the Bench Stock Section to process issues. For the simulation model, the arrival of bench stock issues was considered a controlled variable. The model reflected the fact that an average of 250 bench stock issue requests arrived at the storage area at the start of the work day on Tuesday, Wednesday, and Thursday of each week.

The method of requesting reparable systems for the production repair process was also determined to be a controlled process. The random sample of DOD Form 1348-1s revealed that an average of 80 reparable system issues were received simultaneously in the storage area, at a specified time each day. Therefore, an input of 80 reparable system

issue requests at 0900 hours daily was constructed into the model.

In conjunction with the arrival rates of material, the flow of transactions or line items through the model was divided at specified points by various functions of the warehouse process. A random sample of both the Daily Base Supply Management Reports and the DOD Form 1348-1s for Fiscal Year 1980 supplied information which enabled the divisions or model branching designs to be quantified. For example, it was determined that 15 percent of all receipts require inspection while the remaining 85 percent do not. The Q-GERT model presented in Appendix B illustrates all the branching designs, which were calculated in the same manner.

Server Rates

In the simulation model, the times required to perform warehousing functions or processes by either the warehousemen, inspectors, or mechanized devices are represented by server rates. These server rates were developed by three basic methods. First, if the current process would be unchanged in the proposed material handling system, the present labor standard for that process was used as the server rate in the model. If the process had no present labor standard, then one was developed using time study methods. Secondly, when the proposed warehousing system

radically changed a process, a labor standard was developed using synthetic measurement techniques such as Methods-Times-Measurement (MTM). Finally, in some instances, especially those dealing with mechanized processes, the server times were calculated by examining manufacturer's specifications for equipment or by interviewing knowledeable people in the material handling and warehousing fields.

The statistical foundation of labor standards allows the server rates to be represented as normal distributions with the mean equal to the average server time. Table 1 presents the server rates for the model. As an example of server rate calculations, a time study indicated that the time required to inspect a reparable system is 4.5 minutes with a standard deviation of .4 minutes. The minimum and maximum times were extracted from the time study data. As another example of server rate determination, the manufacturer's specifications indicated a storage/retrieval rate of 60 items per hour for the wire-guided stockpicker. This rate was transformed into a rate of one item per minute for input in the model. The minimum and maximum times were engineering estimates developed by the designers of the material handling system. This server rate was used for all the stockpicker's functions in the model; storage and retrieval of reparable systems and storage and retrieval of large bin items.

TABLE 1

SERVER RATES
(In Minutes)

Nomenclature	Parameter Number in Model	Mean Time	Minimum Time	Maximum Time	Standard Deviation
Receiving					
Open	2	1.5	1	2	.2
Incheck	3	5	4	6	.4
Inspect	4	12	8	16	2
Keypunch	5	1.5	.5	2.5	.5
Small Bin Storage	7	2.4	1.9	3.2	.3
Small Bin Issue	14	1.9	1.6	2.4	.3
Stockpicker	16	1	.75	1.25	.1
Reparable System					
Open and Issue	17	3.3	1.3	5.3	.7
Forklift	8	1	.75	1.25	.1
Open and Incheck	9	3.3	2.5	4.1	.3
Inspect	10	4.5	3.5	5.5	.4
Close	12	3	2	4	.4
Keypunch	11	1.5	.5	2.5	.5

Conveyor Speed -- 200 feet per minute

Summary

As indicated, the majority of data collected came from random sampling of the supply management information system. Even though this data was statistically sound, the findings were presented to the respective section supervisors for agreement or rebuttal. This effort, actually a part of model validation, was accomplished in order to include the eventual model users into the design process and increase their confidence in the model and its results.

CHAPTER IV

MODEL FORMULATION AND MANIPULATION

The proposed model of the material handling system, with the calculated input data parameters, was translated into a Q-GERT network and subsequently coded into a Q-GERT computer program in order to proceed with the simulation process. The network and computer program are contained in Appendices B and C, respectively. The interested reader is referred to Modeling and Analysis Using Q-GERT Networks, by A. Alan B. Pritsker, for a detailed explanation of the network symbols and associated computer-coded statements.

Validation

After developing the computer program, an experimental run was made to verify the simulation model. No errors were detected in the program and the program was determined to be an accurate representation of the Q-GERT network; therefore, the model was considered verified.

A meeting was conducted, at this point in the process, with the principle users of the simulation model for the purpose of validating the model. It was felt that validation at this time would prevent errors and repetition in the experimental testing and analysis phases of the

research. In attendance at this meeting were the Deputy Chief of the Supply Division, the Chief of Warehouse Operations, the Chief of the Storage and Issue Section, and two industrial engineers, all of whom were responsible for the system's design. Areas of discussion were network and model logic, server and arrival rates, parameter definitions, and model objectives. Acceptance of the model by the principle users in attendance at the meeting constituted model validation.

In addition to the validation process, major benefits are derived from the participation of the users of the model in the simulation model development and evaluation process. Top management involvement is a key factor for successful implementation and use of management science models since these managers control the resources within the system's environment.[1] The line managers, who are most familiar with the material handling system, can insure that the model captures the real system. As mentioned in Chapter III, this form of validation increases the users' confidence in the simulation model and its results.

Model Manipulation

It is apparent that the real material handling system will never be empty or in a start-up condition

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[1]See B. W. Holz and J. M. Wroth, "Improving Strength Forecasts: Support for Army Manpower Management," Interfaces, Vol. 10, No. 6 (December 1980), for a discussion of key factors necessary for implementation of management science models.

after implementation. This fact necessitated experimentally determining an equilibrium/start-up condition in order to study the system under realistic conditions. This was accomplished by running the simulation model a total of ten times, with each successive run being extended for a longer period of time. Two specific queues were analyzed because of their critical interaction with the entire network. The average number of items in each queue was plotted against the respective computer run time length (Figure 7 and 8). It is observed that a stable state is not reached until the 3000th time unit. Therefore, in order to obtain a representative sample for experimental testing, the model was run for a simulated 5400 time units, with the first 3000 time units used to reach a steady state condition, and the last 2400 time units used to generate data for the analysis. Each time unit in the simulation represented one minute of real time in the proposed system.

The experimental design of this research included evaluating specified system variables under both normal and surge operating conditions. This design involved testing two models; one with the input variables set at the normal rates as determined in the data collection and analysis phases, and the second model run under surge conditions, that is an increase of 25 percent in the input variables. The surge rate model, besides providing information on future workloads as mentioned in Chapter II, also

Fig. 7. Equilibrium Condition Test Based on Small Bin Issue Queue

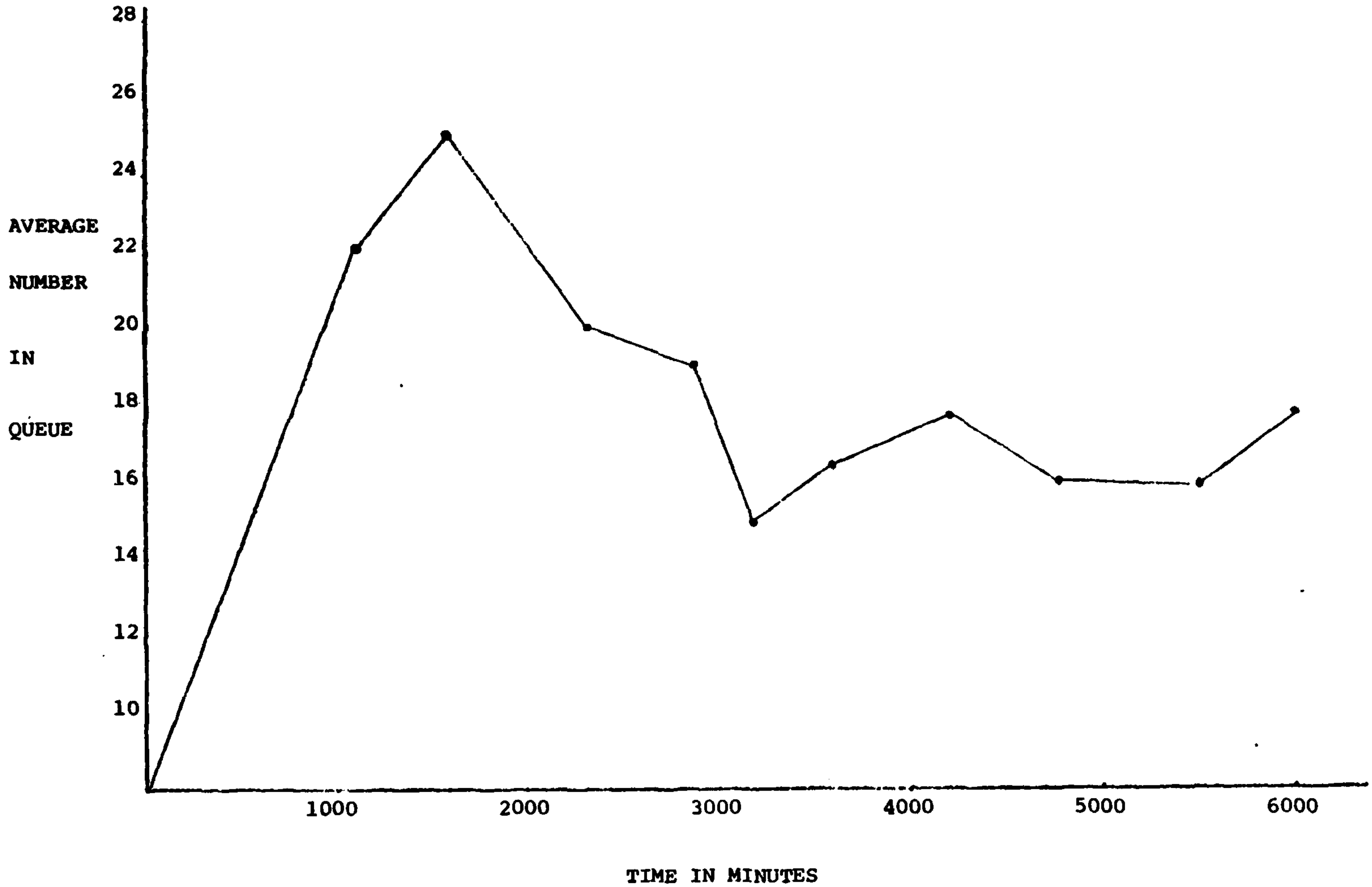


Fig. 8. Equilibrium Condition Test Based on Stockpicker Queue

represents a sensitivity analysis. The sensitivity analysis, which consists of systematically varying the values of input variables and observing the effect upon the model's response variables, is important for three reasons. First, it will demonstrate how sensitive the model results may be to the parameter values used. This is another aid in the model validation process. Second, sensitivity analysis, in the form of varying the input values, can give an indication of the impact of management decisions if the external environment changes. Finally, presenting management and/or the system users with the results of the sensitivity analysis will usually have a very positive psychological effect insofar as obtaining acceptance of the results. The mere fact that we have explored the sensitivity of the model results to changes or errors in parameter estimates, will help reassure the user of the thoroughness of the study (11:235-236).

The input variables that reflected the 25 percent increase in the surge model, were the arrival rates of the trucks to the receiving area, the arrival rates of reparable systems to the receiving process, and the arrival rates of normal, bench stock, and reparable system issues. Since the arrival of reparable systems to receiving, the arrival of reparable system issues to storage, and the arrival of bench stock issues to storage were all determined to be under a controlled process and occur

simultaneously in the warehouse system, the change in the surge value of each variable merely reflected a 25 percent increase. To reflect the surge operating conditions in the simulation model, the number of reparable systems entering the receiving process, the number of reparable system issues and the number of bench stock issues were increased from 80, 80, and 250 to 100, 100, and 312 respectively.

The exponential distributions which represented the arrival rates of trucks to receiving and normal issues to storage were first transformed into the original Poisson distribution. The mean of the Poisson distribution was then increased by 25 percent for both variables and finally, the increased distributions were transformed back into exponential distributions for input in the surge model. The new values of the arrival rates of trucks to receiving and normal issues to storage were 26 minutes between truck arrivals and 2.6 minutes between normal issue arrivals, respectively.

The two models used in the experimental design of this research contained one variation from the proposed material handling system. The parameter which defined the number of parallel servers at the inchecking station of the receiving function was established as 5 by the original system designers (5:137). This parametric value, when placed in the surge model, prevented the computer program

from running successfully. The author was unable to determine if the queue influenced by this parameter in the model was actually exploding or if the interval data collection system of the Q-GERT language package was simply being overloaded. In order to correct the deficiency and provide comparative data for the experimental testing, this parallel server parameter value was set at six for both the normal and surge models.

CHAPTER V

RESULTS AND CONCLUSION

Analysis Overview

The two simulation models, representing normal and surge operating conditions, were analyzed in two phases. The first step was to determine if there was a significant difference between the values of the response variables in the normal and surge models. A test of means using the standardized normal test accomplished this step. If there was a significant difference, the models were analyzed separately in phase two, otherwise they were analyzed as being equal. The second phase of analysis pertained to determining if the allotted space for the queueing of material in the proposed material handling system was adequate. In addition, the utilization of the stockpicker was examined.

Normal and Surge Operating Conditions

The test statistics used in the comparison of the normal and surge operating conditions can be found in Table 2. The means of the response variables generated by the 30 Q-GERT simulations for the normal and surge operating conditions are contained in columns two and three of Table 2, respectively. The first column of Table 2

TABLE 2

QUEUEING SYSTEMS UNDER NORMAL AND SURGE CONDITIONS

Activity	Mean Values Under Normal Conditions	Mean Values Under Surge Conditions	Calculated z Statistics
<u>Queues</u>			
Open	13.747	24.224	17.00
Incheck	3.886	11.557	29.93
Inspect	2.120	7.657	29.96
Keypunch	0.465	0.699	14.34
Storage	0.469	0.737	6.73
Material issue	2.459	4.749	26.44
Reparable systems issue	2.519	4.440	43.30
Dormant issue	31.444	53.359	53.04
<u>Server</u>			
Stockpicker	57.4	71.9	66.10

defines the response variable or activity. The first four queues pertain to the receiving process. The storage queue contains material being conveyed from the receiving area into the storage area. The material and reparable system issue queues represent the movement of material from the storage area into the central distribution area. The document issue queue refers to the build-up of computer generated issue requests for processing in the storage area. The only server rate under analysis was the wire-guided stockpicker.

The means of the response variables indicate the average amount of material in the queues or, for the server rate, the average percentage of time the server was utilized. For example, there was an average of 3.886 line items in the inchecking queue under normal conditions and 11.557 line items in the same queue under surge conditions. Also, there was an average of 31.444 issue requests awaiting processing under normal conditions in the document issue queue, and 53.359 issue requests under surge conditions. The stockpicker statistics reflect an average utilization rate of 57.4 percent during normal conditions and 71.9 percent utilization during surge conditions.

The fourth column of Table 2 reports the calculated standardized normal z statistics used in the hypothesis testing procedure. This statistic was calculated using equation 1 when the sample variances of the two

groups were considered equal and equation 2 when the sample variances were not considered equal (11:220).

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\left(\frac{s_1^2 + s_2^2}{n_1 + n_2}\right)^{\frac{1}{2}}} \qquad \text{(Eq. 1)}$$

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\left(\frac{s_1^2}{n_1 - 1} + \frac{s_2^2}{n_2 - 1}\right)^{\frac{1}{2}}} \qquad \text{(Eq. 2)}$$

where:

$\bar{x}$ = sample mean;

s^2 = sample variances; and

n = sample size.

To determine if the sample variances of the two models' response variables were equal, the *F* statistic was used (11:221). The null hypothesis was that the mean response variable for each queue or server activity of the normal model was equal to the respective mean response variable of the surge model. The alternate hypothesis was that the mean response variables were not equal. The testing procedure involved comparison of the calculated z values to the critical z value with a significance level of .05. Since this is a two-tailed test, the tabled critical z value is 1.96 (11:373). If the calculated value of z is less than the critical value of z, then the null hypothesis

is not rejected. If the calculated value of z is equal to or greater than the critical value of z, then the null hypothesis is rejected. Mathematically, this would be stated as:

$$H_0: \bar{x}_1 = \bar{x}_2$$

$$H_1: \bar{x}_1 \neq \bar{x}_2$$

decision rule:

If $z < z^*$; fail to reject H_0

If $z \geq z^*$; reject H_0

where: z^* = critical z at .05 level of significance.

In all cases, the null hypothesis was rejected and, therefore, the 25 percent increase in normal operating condition was considered to cause a significant change in the behavior of the system.

Queue Analysis

The mean statistics in Table 2 are important to management because the average build-up of material in the specified queues and stockpicker utilization constitute the expected system's behavior for the majority of the time. The uncertainty that is present with implementation of the new system can be greatly reduced by understanding the system's behavior as it will be for the majority of the time. Equally important, the proposed system must be able to adapt to the periods of time in which there are maximum

build-ups at queues and strains on the server utilization. If the system can cope with these periods of intensity, then obviously, it can cope with the average periods of operation.

The second phase of the analysis involved comparing the material queueing space allocated by the system designers to the maximum amount of space required at any one time for material queueing as reported in the Q-GERT simulations. Since a significant difference was found between the two models, they were analyzed separately. The allocated space for material queueing was determined by converting line items into pallet floor space and linear feet on conveyors or vice versa, depending on the process being analyzed. Table 3 shows these calculations and information on maximum space required as generated by the Q-GERT simulations that were used in the analysis.

A random sample of the present material handling system indicated that an average of three line items can be placed in one tote pan. Each tote pan, which will also be utilized in the proposed system, occupies two linear feet of conveyor space. This information determined the conversion factor of three line items per two linear feet of conveyor. The random sample also indicated that an average of 20 line items can be placed on a standard pallet (40"x48"). A reparable system, in its shipping container, occupies three linear conveyor feet. These

TABLE 3

ANALYSIS OF AVAILABLE FLOOR/CONVEYOR SPACE

Process	Space Available	Maximum Space Required	
		Normal Condition	Surge Condition
Receiving			
Open	480 line items	127 line items	187 line items
Incheck		64 line items	113 line items
Inspect		26	47
Keypunch		10	9
Total	240 line items	100 line items	169 line items
Storage	135 line items	10 line items	15 line items
Issue to Distribution Area			
Material issue		37 linear feet (56 line items)	49 linear feet (73 line items)
Reparable systems issue		87 linear feet (29 systems)	108 linear feet (36 systems)
Total	70 linear feet	124 linear feet	157 linear feet

statistics, when combined with the information on space availability taken from the proposed system design drawings, provided the calculations represented in the Space Available column in Table 3 (5:58).

The statistics from Table 3 indicate that no problem in queueing space is present, under either the normal conditions or the surge conditions, for the receiving area. There is space available for 480 palletized line items waiting to be opened in the receiving area. The simulations indicate that the expected maximum amount of line items in this area is only 127 and 187 for normal and surge operating conditions, respectively. The receiving area, consisting of the incheck, inspect, and keypunch activities, has a conveyor capacity of 240 line items and an expected requirement for only 100 line items under normal conditions and 169 line items under surge conditions. The expected maximum requirement for line items moving from the receiving area to storage is 10 line items under normal conditions and 15 line items under surge conditions. There is no apparent space problem in this area either, since there is a space available for 135 line items.

Material and reparable system issues, moving from storage to the central distribution area, does appear to present a potential problem situation. There is a capacity for 70 linear feet and an expected maximum requirement of 124 linear feet during normal conditions and 157 linear

feet during surge conditions. This inadquate space availability creates a bottleneck on the conveyor. Further investigation, however, provides the insight that this bottleneck is intermittent and temporary. The situation occurs at the electric eye-gating mechanism as shown in Figure 4. At this gate, reparable systems are sent straight ahead and other issued material is diverted to the right for temporary storage in shelves, awaiting distribution to production areas or to other base activities. Once past the gate, the reparable systems enter a queue to be removed from their containers and issued to the production area. This reparable system queue has a maximum capacity of nine systems and once the maximum is reached, the gating mechanism is blocked. This blockage of the gating mechanism develops because of the simultaneous issuing of 80 reparable systems once a day. As seen in Table 2, the average queue size in this area is 2.459 line items under normal conditions and 4.749 under surge conditions for the majority of the time. Therefore, a bottleneck situation occurs only once a day at a specific time. The labor standards, developed for the removal of the reparable systems from their container and subsequent issue to production, indicate that the 80 systems can be processed in approximately two hours. Thus, the bottleneck situation has a probability of occurring only during a specific, two-hour period. Management awareness of this potential problem area will allow them to plan

accordingly. They might chose to schedule around the bottleneck, revise the proposed material handling system to correct the situation, or add warehousemen to this area to decrease the reparable system issue process time.

Server Utilization Analysis

The proposed system designers established a utilization rate of 60 percent for the wire-guided stockpicker to allow for preventive maintenance, unscheduled maintenance, and utilization in other areas. The 57.4 percent utilization rate, as seen in Table 2 for simulated normal conditions, is within the established standard. However, the standard is exceeded during surge operating conditions. Therefore, during anticipated surge conditions, management must be aware that preventive actions must be taken or the stockpickers will not function as desired. Such actions could be the temporary or permanent acquisition of a similar piece of equipment, rescheduling of vehicle maintenance, or using conventional material handling equipment in place of the stockpicker when applicable.

Conclusion

The purpose of this research was to study the behavior of a proposed material handling system under simulated operating conditions in order to gain information on the system's operating characteristics. The experimental design of the study was used to analyze specific response

variables under both normal and surge operating conditions. This analysis was conducted using Q-GERT computer simulation models.

The analysis determined that a 25 percent increase in operating conditions has significant effects on the proposed system and its components. Problem areas were identified in the queueing of material and reparable systems issues, and in the stockpicker utilization rate under surge operating conditions. It is the author's opinion that these two problem areas should be addressed by management and further research in each area should take place before the proposed material handling system is implemented.

While the research objective has been reached, the author feels that the warehouse simulation model is still a useful tool for management. It has many possible future uses for management planning and decision making. With minor modifications, the model could be used to analyze further modifications and additions to the warehousing process such as: additional wire-guided stockpicker routes, modified storage location layouts, changes in computer input/output transfers, and automated storage and retrieval systems.

APPENDICES

APPENDIX A

GLOSSARY OF TERMS

Bin--a location for storage of loose issue items.

Gravity flow storage racks--storage racks consisting of roller tracks on the shelves which are at a slight angle. The storage material mentioned is placed in the rear of the rack and flows to the front by the force of gravity to be retrieved when needed.

Issues--material going from supply warehouse area to the production area or other base activities.

Line items--a single entry in the supply inventory system. The method for identifying material within warehousing system.

Receipts--material from external or internal sources arriving into the supply inventory.

Reparable systems--inertial guidance systems to be repaired at AGMC.

Serviceable systems--inertial guidance systems that have completed the repair cycle and are ready for use.

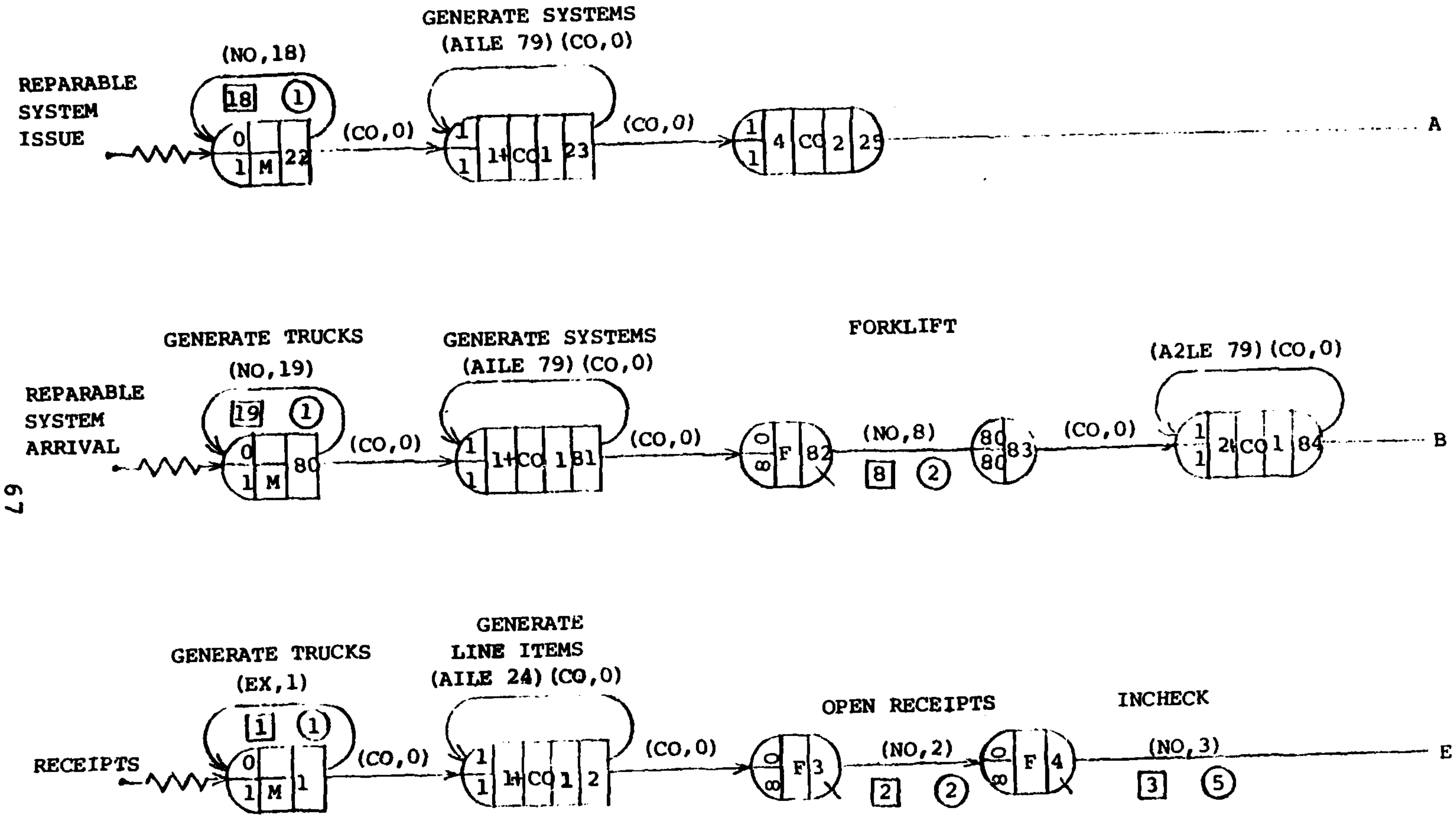
Single point storage--concept where the user of material, if he is the sole user, is responsible for storage and inventory of the item. Presently material used only at AGMC can be stored and inventoried by other ALCs.

Stockpicker (wire-guided)--forklift which carries the operator to the shelf height in order to reach material. The wire-guided systems refers to inlaid wire between storage racks in order to pick up impulses to steer the stockpicker.

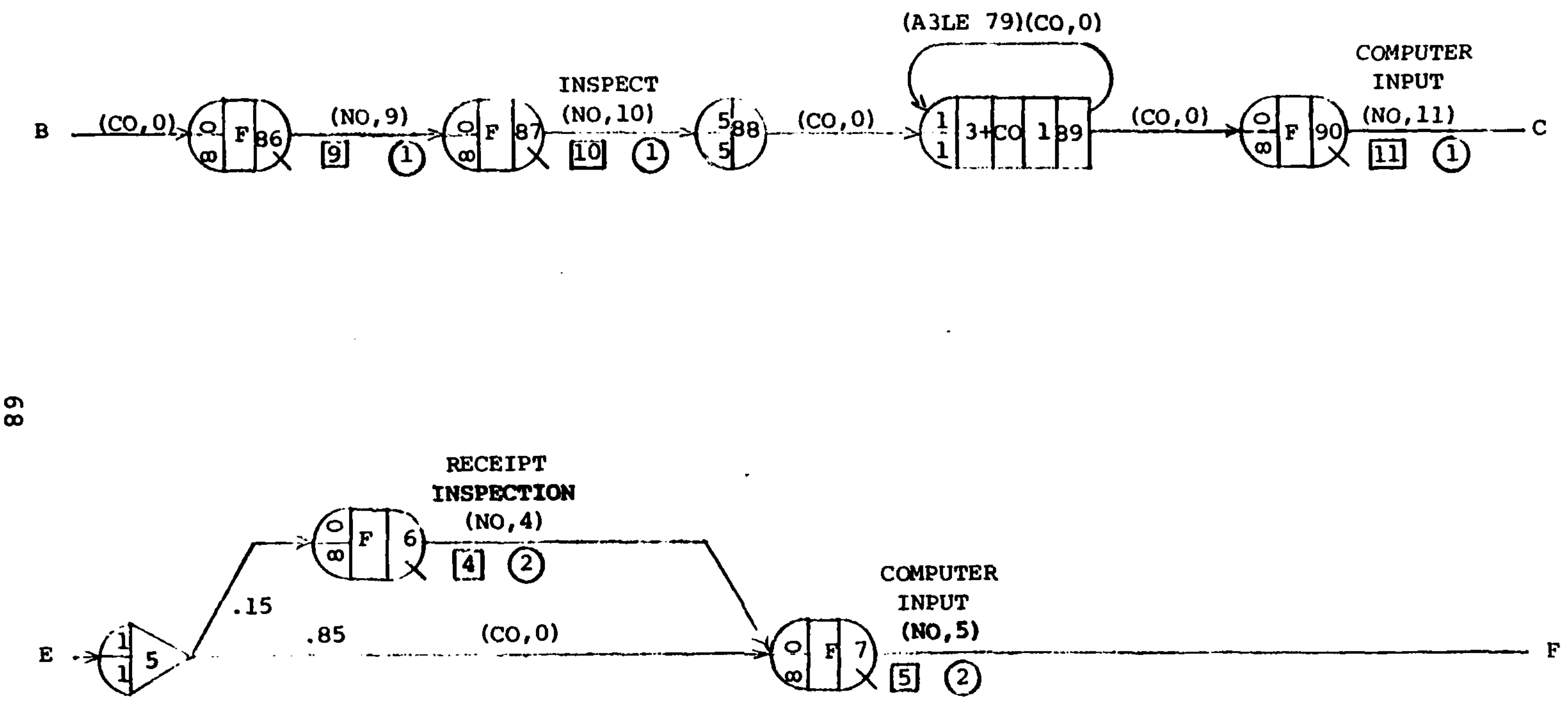
Turn-ins--material entering supply inventory from internal sources.

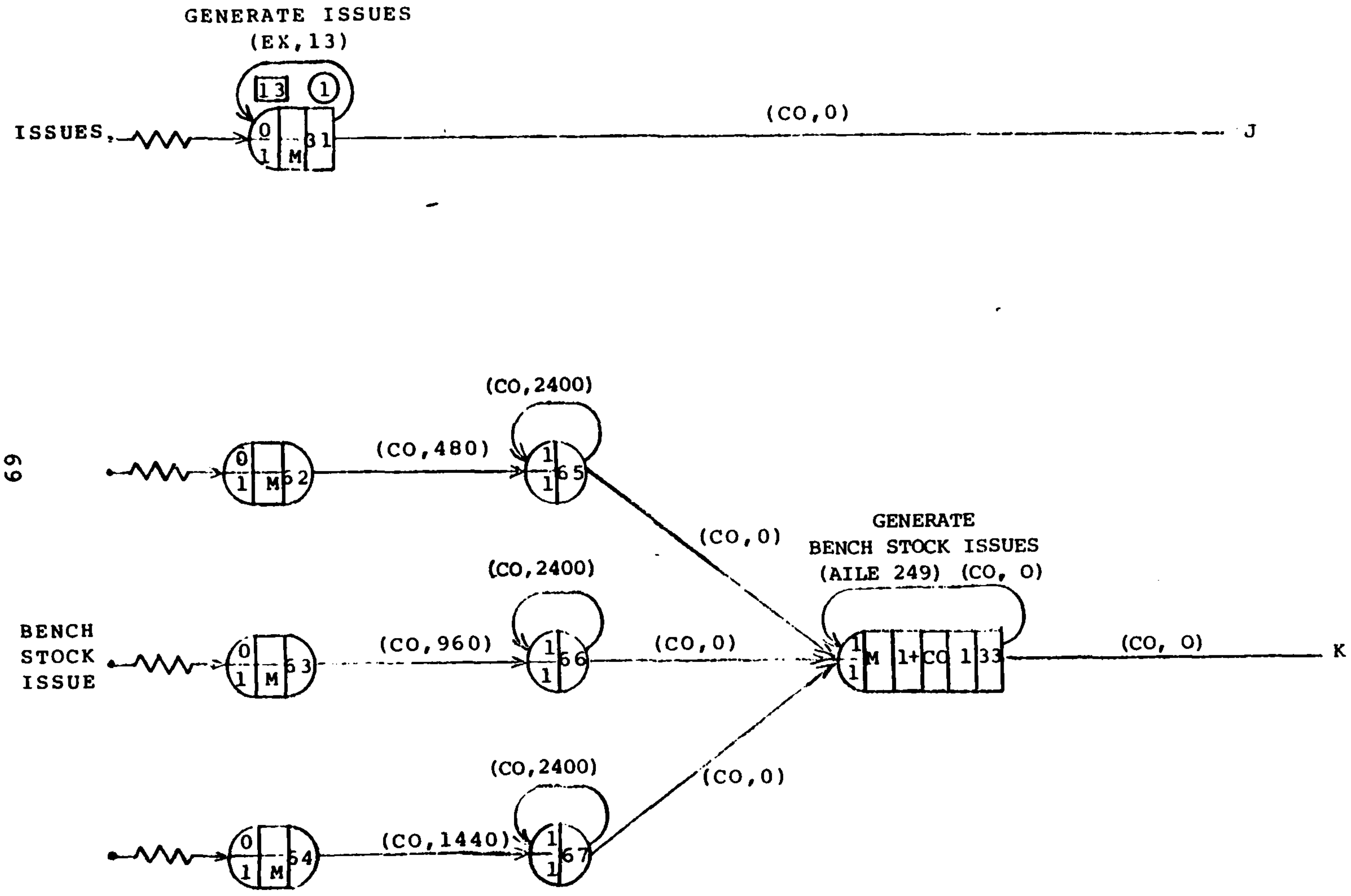
APPENDIX B

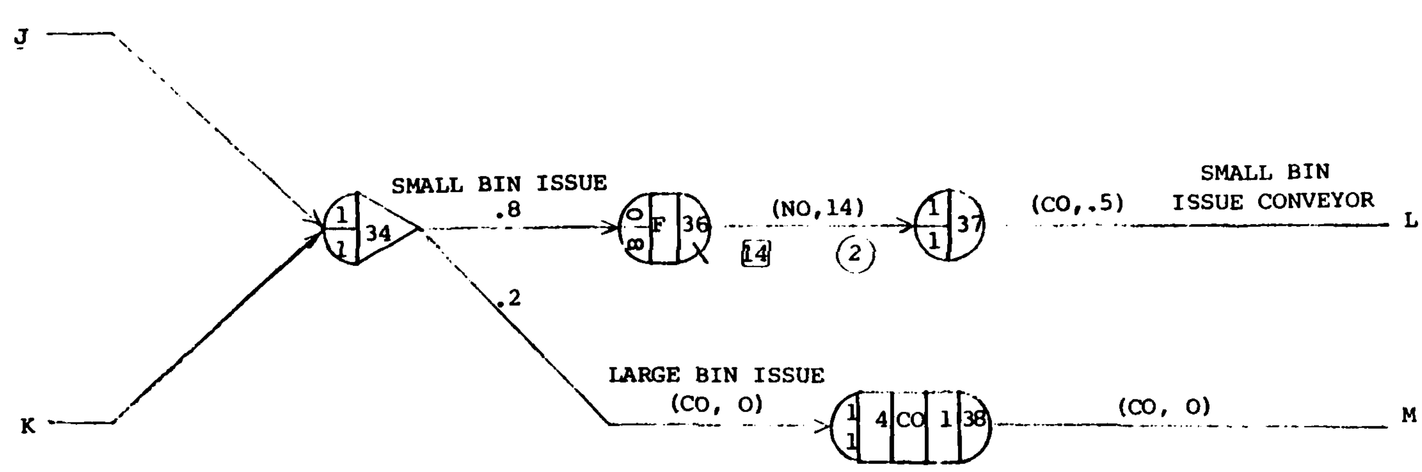
Q-GERT NETWORK

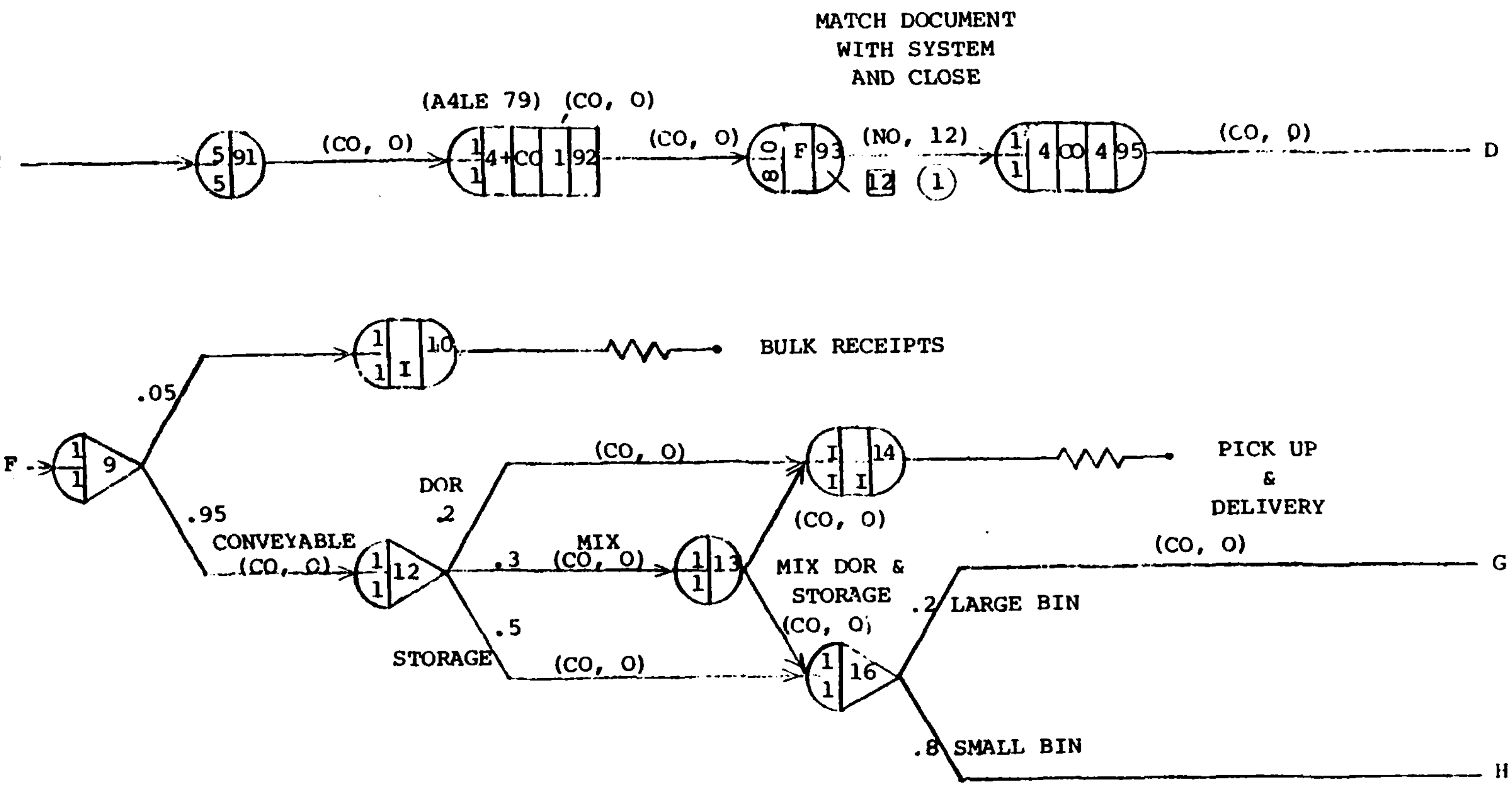


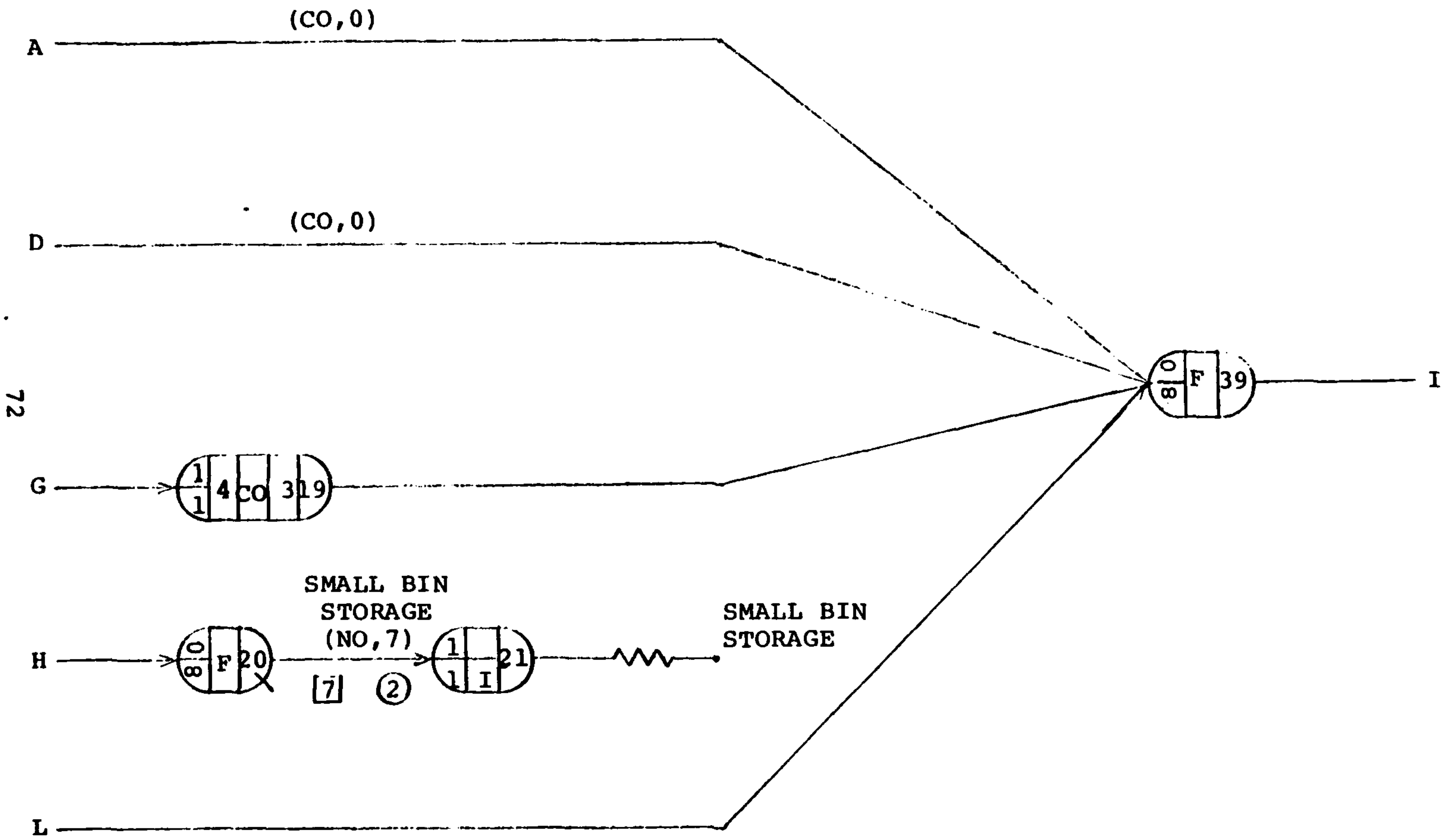
GENERATE SYSTEMS
(AILE 79) (CO,0)
(NO,18)
REPARABLE SYSTEM ISSUE
(CO,0)
(CO,0)
A
GENERATE TRUCKS
(NO,19)
GENERATE SYSTEMS
(AILE 79) (CO,0)
FORKLIFT
(A2LE 79) (CO,0)
REPARABLE SYSTEM ARRIVAL
(CO,0)
(CO,0)
(NO,8)
(CO,0)
B
GENERATE
LINE ITEMS
(AILE 24) (CO,0)
GENERATE TRUCKS
(EX,1)
OPEN RECEIPTS
INCHECK
RECEIPTS
(CO,0)
(CO,0)
(NO,2)
(NO,3)
E

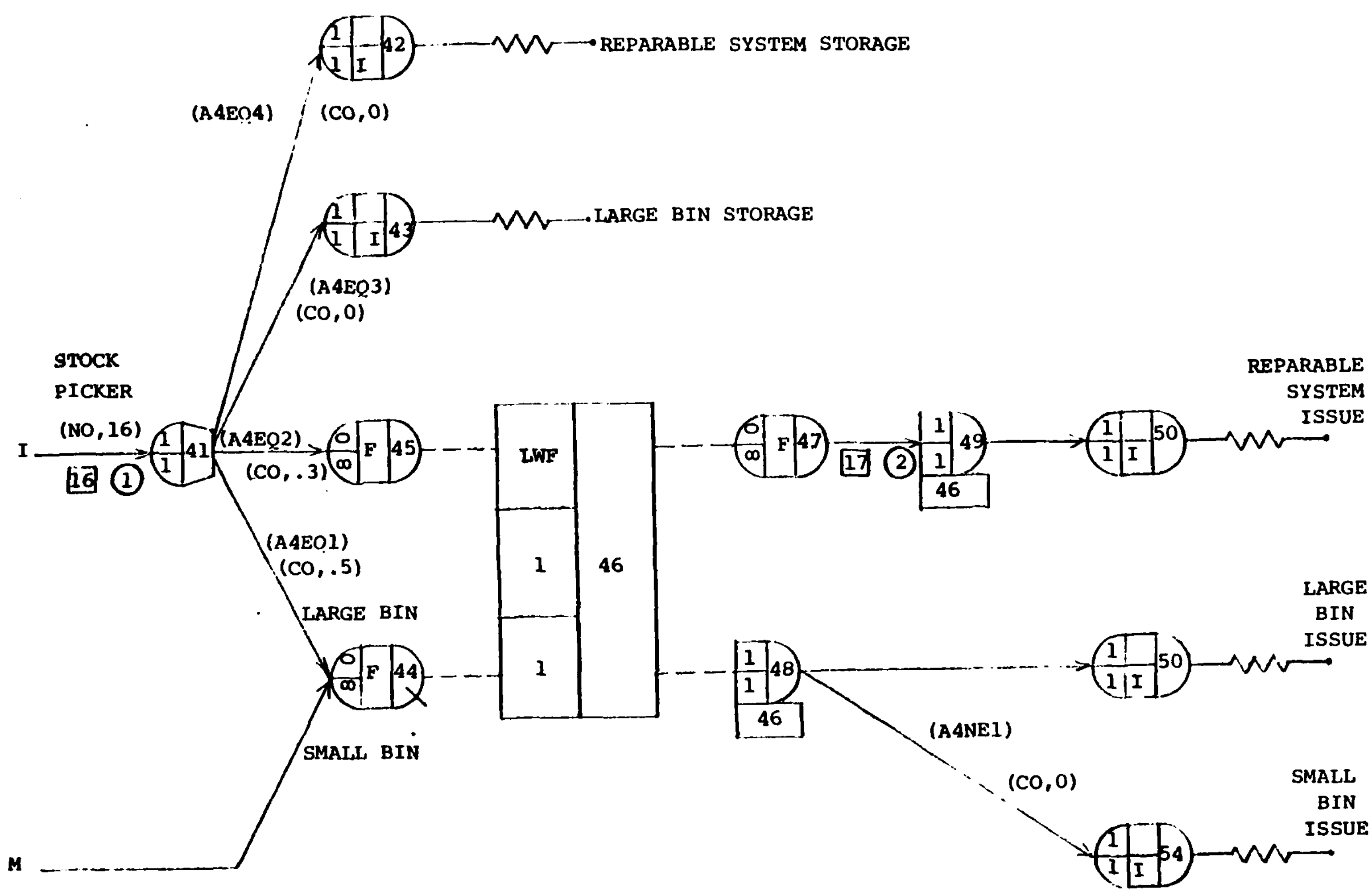

(A3LE 79)(CO,0)
COMPUTER
INPUT
INSPECT
(NO,10)
B
(CO,0)
F
86
(NO,9)
9
1
87
10
1
5
88
5
(CO,0)
1
1
3+CO
1
89
(CO,0)
F
90
(NO,11)
11
1
C
RECEIPT
INSPECTION
(NO,4)
F
6
4
2
COMPUTER
INPUT
(NO,5)
E
1
1
5
.15
.85
(CO,0)
F
7
5
2
F


GENERATE ISSUES
(EX,13)
ISSUES
(CO,0)
J
(CO,2400)
(CO,480)
(CO,0)
GENERATE
BENCH STOCK ISSUES
(AILE 249) (CO, 0)
(CO,2400)
BENCH
STOCK
ISSUE
(CO,960)
(CO,0)
(CO, 0)
K
(CO,2400)
(CO,1440)
(CO,0)


J
K
SMALL BIN ISSUE
.8
.2
(NO,14)
14
2
(CO,.5)
SMALL BIN
ISSUE CONVEYOR
L
LARGE BIN ISSUE
(CO, O)
(CO, O)
M


C
D
(CO, O)
(A4LE 79)
(CO, O)
(CO, O)
(NO, 12)
(CO, O)
MATCH DOCUMENT
WITH SYSTEM
AND CLOSE
BULK RECEIPTS
F
.05
.95
CONVEYABLE
(CO, O)
DOR
.2
.3
MIX
(CO, O)
.5
STORAGE
(CO, O)
(CO, O)
(CO, O)
MIX DOR &
STORAGE
(CO, O)
PICK UP
&
DELIVERY
(CO, O)
.2
LARGE BIN
.8
SMALL BIN
G
H


A
D
G
H
L
(CO,0)
(CO,0)
SMALL BIN
STORAGE
(NO,7)
SMALL BIN
STORAGE
I



REPARABLE SYSTEM STORAGE
LARGE BIN STORAGE
(A4EQ4)
(CO,0)
(A4EQ3)
(CO,0)
STOCK
PICKER
(NO,16)
I
16
1
41
(A4EQ2)
(CO,.3)
45
LWF
1
1
46
47
17
2
49
46
50
REPARABLE
SYSTEM
ISSUE
(A4EQ1)
(CO,.5)
LARGE BIN
44
SMALL BIN
M
48
46
50
LARGE
BIN
ISSUE
(A4NE1)
(CO,0)
54
SMALL
BIN
ISSUE

APPENDIX C

Q-GERT SIMULATION PROGRAM LISTING

```
GEN,HARP,(8)8,50000,5400,30,(13)3000,6*
SOU,1,0,1,A*
ACT,1,1,EX,1,1/TRUCKS*          TRUCK ARRIVAL RATE
PAR,1,33,8,90*
ACT,1,2,*
REG,2,1,1,A*
VAS,2,1+,CO,1*
ACT,2,2,(9)A1.LE.24*            GENERATE LINE ITEMS
ACT,2,3*
QUE,3/QOPEN,(8)2,2*             QUEUE OPEN PACKAGES
ACT,3,4,NO,2,2/OPEN,2*          OPEN PACKAGES FOR RECEIVING
PAR,2,1.5,1,2,.2*
QUE,4/QINCHECK,(8)2,2*          QUEUE INCHECK
ACT,4,5,NO,3,3/INCHECK,6*
PAR,3,5,4,6,.4*
REG,5,1,1,P*
ACT,5,6,(8).15*                 INSPECT BRANCH
ACT,5,7,(8).85*                 NON INSPECTION BRANCH
QUE,6/QINSPECT,(8)2,2*          QUEUE INSPECTION OF RECEIPT
ACT,6,7,NO,4,4/INSPECT,2*
PAR,4,12,8,16,2*
QUE,7/QKEYPUN,(8)2,2*           QUEUE KEYPUNCH
ACT,7,9,NO,5,5/KEYPUNCH,2*
PAR,5,1.5,.5,2.5,.5*
REG,9,1,1,P*
ACT,9,10,(8).05*                BULK RECEIPTS
ACT,9,12,(8).95*                CONVEYABLE RECEIPTS
SIN,10/BULKREC,1,1,,I,5,10*     BULK RECEIPTS END
REG,12,1,1,P*
ACT,12,14,(8).2*                DUE OUTS
ACT,12,13,(8).3*                MIX
ACT,12,16,(8).5*                STORAGE
REG,13,1,1*
ACT,13,14*
ACT,13,16*
SIN,14/P&D,1,1,,I,5,10*         DUE OUTS END AT P&D
REG,16,1,1,P*
ACT,16,19,(8).2*                LARGE BIN STORAGE
ACT,16,20,(8).8*
QUE,20/QSTORSB,(8)2,2*          QUEUE SMALL BIN STORAGE
ACT,20,21,NO,7,7/STOR,2*
PAR,7,2.4,1.9,3.2,.3*
SIN,21/SBSTOR,1,1,,I,5,10*      SMALL BIN STORAGE END
REG,19,1,1*
VAS,19,4,CO,3*                  LARGE BIN PAR 4=3
ACT,19,39*
QUE,39/QSTKPICK,(8)2,2*         WAIT FOR STOCKPICKER
```

```
ACT,39,41,NO,16,16/STOCKPKER*
PAR,16,1,.75,1.25,.1*
REG,41,1,1,A*
ACT,41,42,(9)A4.EQ.4*          REPARABLES TO STORE
ACT,41,43,(9)A4.EQ.3*          LARGE BIN TO STORE
ACT,41,45,CO,.3,(9)A4.EQ.2*    REPARABLES TO ISSUE
ACT,41,44,CO,.5,(9)A4.EQ.1*    LARGE BIN TO ISSUE
SIN,42/REPSTO,1,1,,I,5,10*     REPARABLE STORAGE END
SIN,43/LBSTO,1,1,,I,5,10*      LARGE BIN STORAGE END
QUE,44/QLB,(8)2,2,46*
QUE,45/QREPS,(8)2,2,46*
RES,1/SPACE,9,46*              GATING
ALL,46,LWF,1,1,45/47,44/48*
FRE,49,,1,1,46*
FRE,48,F,1,1,46*
QUE,47/QOPENSYS,(8),2,2*       QUEUE OPEN SYSTEM FOR ISSUE
ACT,47,49,NO,17,17/OPENSYS,2*  OPEN SYSTEM FOR ISSUE
PAR,17,3.3,1.3,5.3,.7*
ACT,49,50*
SIN,50/REPISS,1,1,,I,5,10*     REPARABLES ISSUED END
ACT,48,52,(9)A4.EQ.1*          LB ISSUE
ACT,48,54,(9)A4.NE.1*          SB ISSUE
SIN,52/LBISS,1,1,,I,5,10*      LARGE BIN ISSUE END
SIN,54/SBISS,1,1,,I,5,10*
SOU,22,0,1,A*
ACT,22,22,NO,18,18/REPISS*
PAR,18,480,480,600,40*
ACT,22,23*
REG,23,1,1,A*
VAS,23,1+,CO,1*
ACT,23,23,(9)A1.LE.79*
ACT,23,25*
REG,25,1,1*
VAS,25,4,CO,2*                 REP ISSUE PAR 4=2
ACT,25,39*
SOU,31,0,1,A*
ACT,31,31,EX,13,13/ISSUE*
PAR,13,3.2,2.4,4.8*
ACT,31,34*
SOU,62,0,1,A*
SOU,63,0,1,A*
SOU,64,0,1,A*
ACT,62,65,CO,480*
ACT,63,66,CO,960*
ACT,64,67,CO,1440*
REG,65,1,1,A*
REG,66,1,1,A*
REG,67,1,1,A*
ACT,65,65,CO,2400*
ACT,66,66,CO,2400*
```

```
ACT,67,67,CO,2400*
ACT,65,33*
ACT,66,33*
ACT,67,33*
REG,33,1,1,A,M*
VAS,33,1+,CO,1*
ACT,33,33,(9)A1.LE.249*
ACT,33,34*
REG,34,1,1,P*
ACT,34,38,(8).2*
ACT,34,36,(8).8*                SMALL BIN ISSUE
REG,38,1,1*
VAS,38,4,CO,1*                  LARGE GIN ISSUE PARA4=1
ACT,38,39*
QUE,36/QSBISS,(8)2,2*           QUEUE SMALL BIN ISSUE
PAR,14,1.9,1.6,2.4,.3*
ACT,36,37,NO,14,14/ISSUE,2*
REG,37,1,1,A*
ACT,37,44,CO,.5*
SOU,80,0,1,A*
ACT,80,80,NO,19,19/REPS*
PAR,19,480,420,540,20*          SYSTEMS ARRIVE EVERYDAY
ACT,80,81,CO,240*               4 HOUR DELAY
REG,81,1,1,A,M*
VAS,81,1+,CO,1*
ACT,81,81,(9)A1.LE.79*          GENERATE 80 SYSTEMS
ACT,81,82*
QUE,82/QFKLT*
ACT,82,83,NO,8,8/FKLT*
PAR,8,1,.85,1.25,.1*
REG,83,80,80,(7)L*
ACT,83,84*
REG,84.1,1,A*
VAS,84,2+,CO,1*
ACT,84,84,(9)A2.LE.79*
ACT,84,86*
QUE,86/OPEN*
ACT,86,87,NO,9,9/OPEN*          OPEN SYSTEM CONTAINER
PAR,9,3.3,2.5,4.1,.3*
QUE,87/QINSP,(8)2,2*            WAIT FOR INSPECTION
ACT,87,88,NO,10,10/INSPECT*     INSPECT SYSTEMS
PAR,10,4.5,3.5,5.5,.4*
REG,88,5,5,(7)L*
ACT,88,89*
REG,89,1,1,A*
VAS,89,3+,CO,1*
ACT,89,89,(9)A3.LE.4*
ACT,89,90*
QUE,90/KYPUN,(8)2,2*            QUEUE FOR KEYPUNCH
ACT,90,91,NO,11,11/COMPUTER*    INPUT TO COMPUTER
```

```
PAR,11,1.5,.5,2.5,.5*
REG,91,5,5,(7)L*
ACT,91,92*
REG,92,1,1,A*
VAS,92,4+,CO,1*
ACT,92,92,(9)A4.LE.4*
ACT,92,93*
QUE,93/QMATCH,(8)2,2*          QUEUE MATCH DOC TO SYSTEM
ACT,93,95,NO,12,12/CLOSE*      MATCH DOCUMENT AND CLOSE
PAR,12,3,2,4,.4*
REG,94,4,4*
ACT,94,95*
REG,95,1,1*
VAS,95,4,CO,4*                 REPS RECEIVED PARA 4=4
ACT,95,39*
FIN*
```

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Anderson, David R., Dennis J. Seeney, and Thomas A. Williams. An Introduction to Management Science: Quantitative Approaches to Decision Making. St. Paul MN: West Publishing Co., 1979.

2. Barton, Richard F. A Primer on Simulation and Gaming. Englewood Cliffs NJ: Prentice-Hall, Inc., 1975.

3. Chou, Ya-lun. Statistical Analysis. New York: Holt, Rinehart, and Winston, Inc., 1969.

4. Dorough, Captain Robert E., USAF, and Captain Robert H. Holliway, USAF. "A Simulation Study of Checkout Operations at the Wright-Patterson AFB Commissary." Unpublished master's thesis. LSSR 6-80, AFIT/SL, Wright-Patterson AFB OH, June 1978.

5. Harp, Darwin, and Alfred Soltesz. "Material Handling Study: 2803d Air Base Group Supply & Transportation Division." Unpublished research report, unnumbered, Newark Air Force Station OH, 1979.

6. Hillier, Frederick S., and Gerald J. Lieberman. Operations Research. San Francisco: Holden-Day, Inc., 1974.

7. Inspector General, AFLC. Management Effectiveness Inspection Report. Newark Air Force Station OH, June 1978.

8. Neter, John, William Wasserman, and G. A. Whitmore. Applied Statistics. Boston: Allyn and Bacon, Inc., 1979.

9. Phillips, Don T. "Simulation of Material Handling Systems: When and Which Methodology?" Industrial Engineering, September 1980, pp. 65-77.

10. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks. New York: Halsted Press, 1979.

11. Shannon, Robert E. Systems Simulation the Art and Science. Englewood Cliffs NJ: Prentice-Hall, Inc., 1975.

12. U.S. Department of the Air Force. Air Force Mechanized Materials Handling Systems. AFR 71-11. Washington: Government Printing Office, 15 January 1979.

13. White, John A. "Increasing Productivity through Improved Material Handling." Professional seminar lecture, American Institute of Industrial Engineers, Canton OH, October 13, 1979.

14. ________. "Increasing Productivity through Improved Material Handling." Unpublished report, unnumbered, American Institute of Industrial Engineers Seminar, Canton OH, October 13, 1979.

B. RELATED SOURCES

Robinson, Willis C. III. "Investigation of the Effect of Proposed Modifications to an Automated Materials Handling System Using a GPSS Simulation." Unpublished technical report, DARCOM-ITC-02-08-76-202, DARCOM Intern Training Center, Red River Army Depot, Texarkana TX, May 1976.

Rosenthal, Ronald J. "Investigation of an Automated Materials Handling System Using a GPSS Simulation." Unpublished technical report, DARCOM Intern Training Center, Red River Army Depot, Texarkana TX, November 1976.

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